

# Stock Assessments: The Science of Fisheries



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# PRESENTATION OUTLINE

- **Mandate for Assessments**
- **Stock Assessment Goals**
- **Data Requirements**
- **Assessment Methods**
- **Stock Productivity & Fishery Control Rules**
- **Rebuilding Analyses**
- **Risk Assessment**
- **Data-Poor Situations**
- **Ecosystem Considerations**

# Mandate From MSFCMA

- National Standard 1:
  - Conservation and management measures shall *prevent overfishing* while achieving...the *optimum yield* from each fishery...
- Fishery Management Plans must:
  - specify objective and measurable criteria for identifying when a fishery is overfished
    - how the criteria were determined
    - relationship of criteria to reproductive potential
- Thus, comprehensive and accurate scientific information is required.

# Stock Assessment Goals

# Stock Assessment Defined

- Collecting, analyzing, and reporting demographic information for the purpose of determining the effects of fishing on fish populations
- Key Concepts / Jargon
  - Stock; Population; Unit
  - Abundance; Biomass
  - Reproductive Potential; Spawning Biomass
  - Recruitment; Yearclass; Cohort
  - Fishery
  - Fishing mortality ( $F$ ); Exploitation Rate

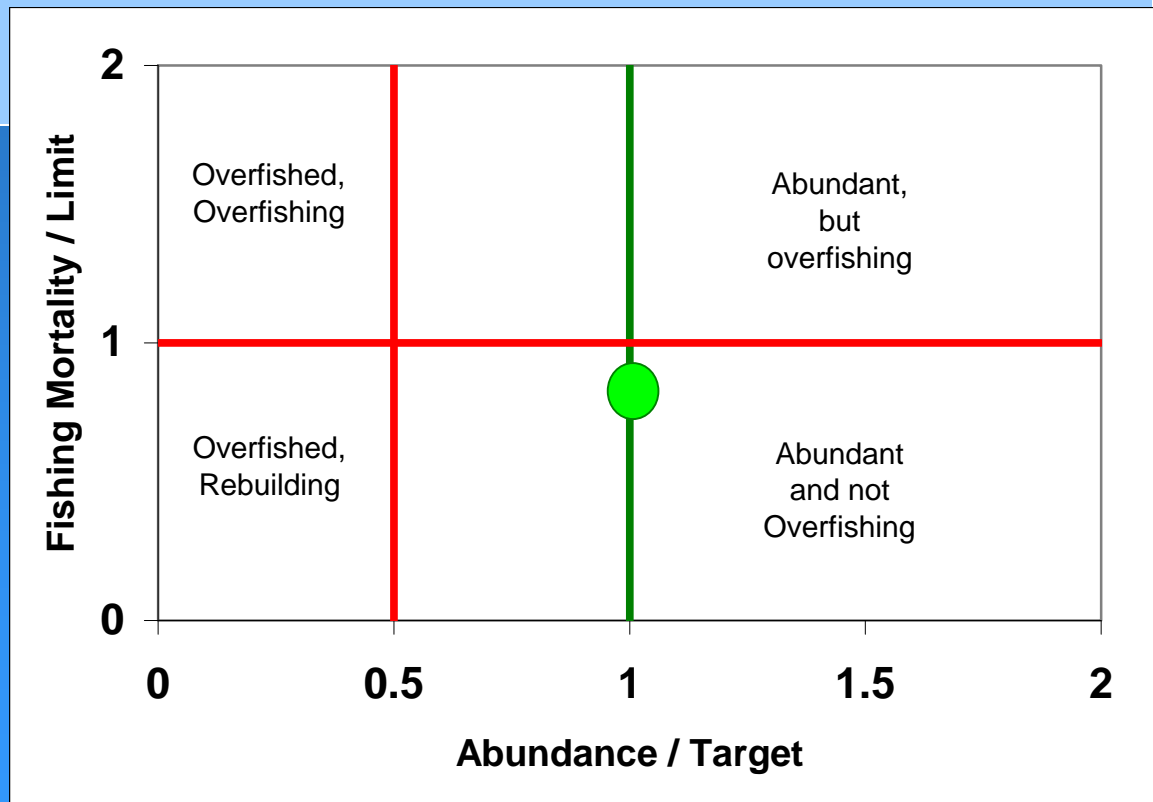
# Long-Term Management Advice



- Optimum Yield: What harvest level would maximize long-term benefits while protecting marine ecosystem?
- What harvest level will allow a stock to rebuild to its target abundance level?
- Are ecosystem components adequately protected?

# Status Determinations

- Did overfishing occur last year?
- Is abundance below the overfished limit?



# Pro-Active, Short-Term Advice

What level of catch next year would implement the target harvest policy?

What level of catch next year has no more than a **X%** chance of causing overfishing?

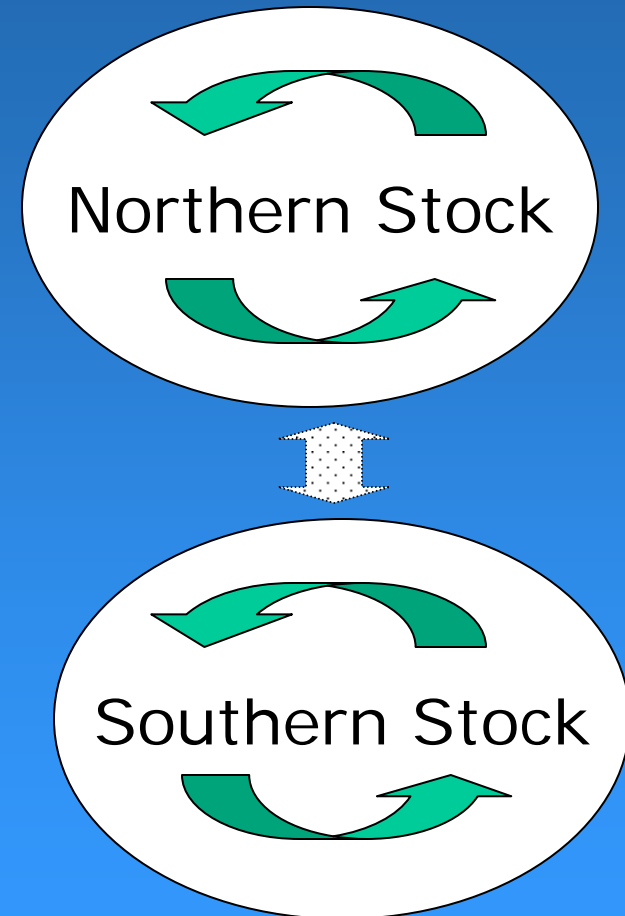
Control Rule: Formula that calculates future target catch level from expected biomass level



# Data Requirements

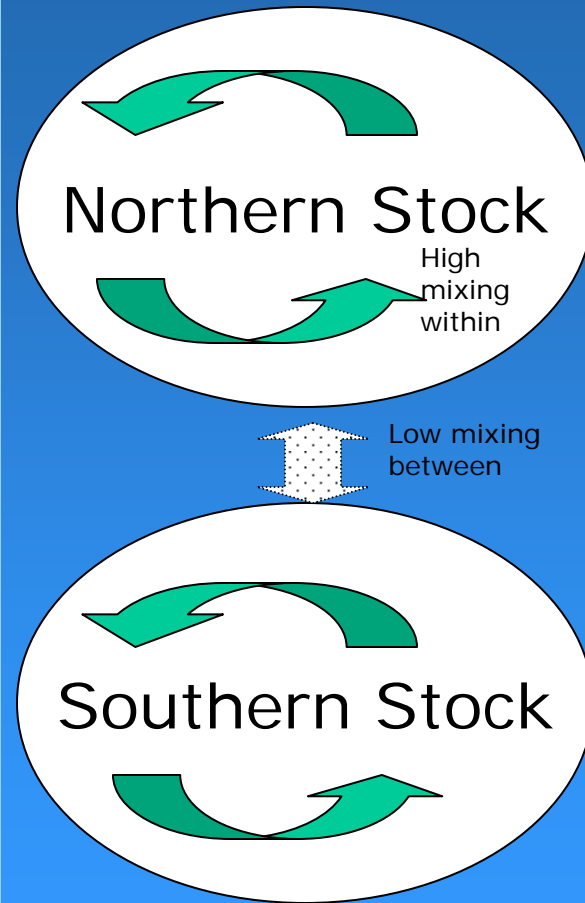
# What is a "Stock"?

- A group of individuals of the same species
- That inhabit the same geographic region
- And that interbreed when mature
- Multi-species complex  $\neq$  true biological stock



# "Stock" Issues

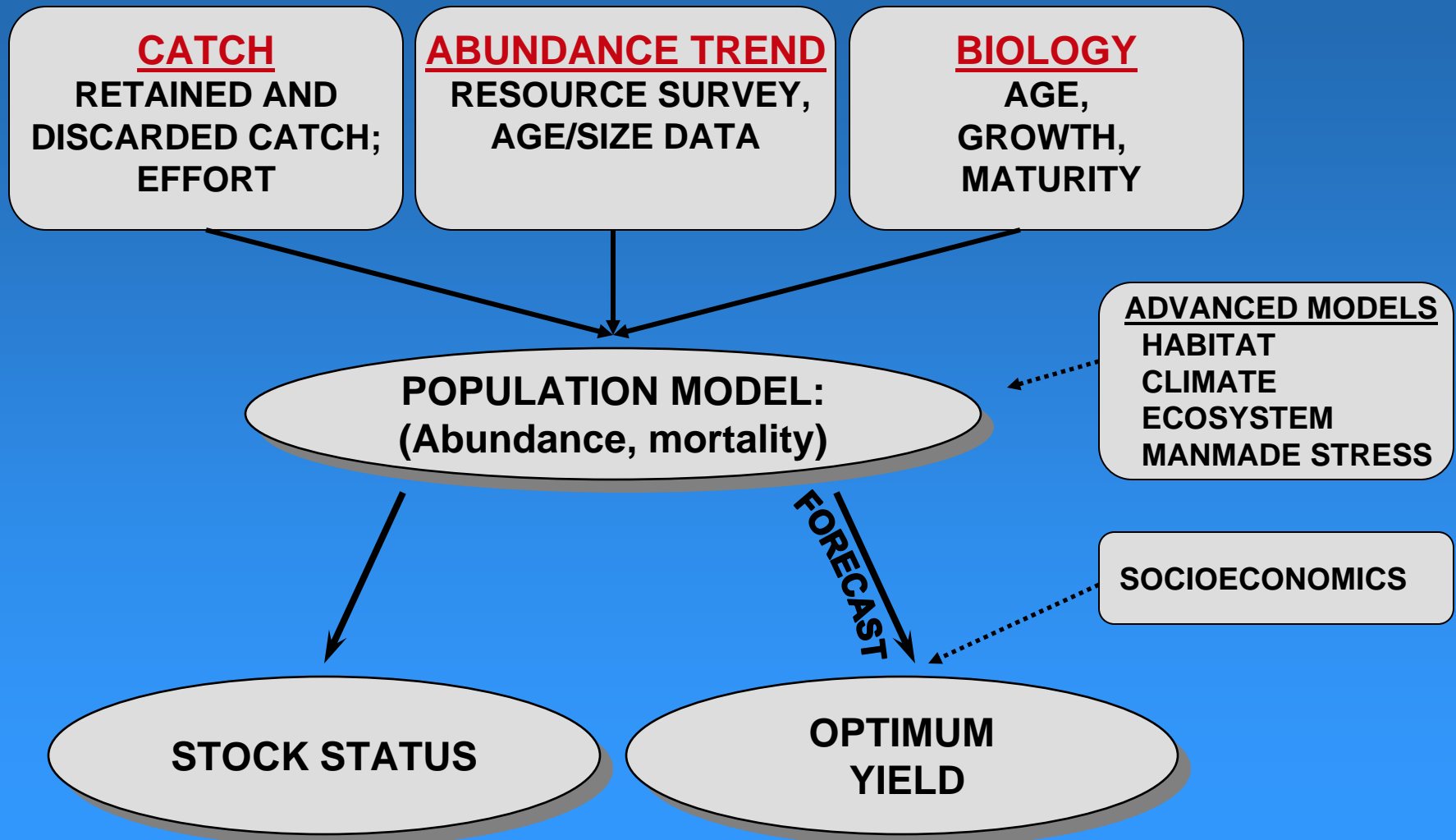
- Assessment models assumes high mixing within stock and negligible mixing between stocks
- Smaller management units guard against localized depletion, but assessment data needs go up
- Larger management unit still needs stock-specific assessments



# Stock Assessment Requirements

- **Biology:** 2 yr old anchovy or 60 yr old rockfish?
- **Catch:** What's being removed by fishing?
- **Abundance:** Stable, or trending?

# Stock Assessment Process



# Total Catch

- A dead fish is a dead fish; count 'em all
  - Commercial retained
  - Commercial discard
  - Recreational kept
  - Recreational released
  - %Survival of discard & released

# Fisheries Information System

- Commercial fishing effort, catch, and value
  - Dealer reports (fish tickets)
  - Vessel trip reports (logbooks)
- Usually based on a census of all landings
- Size and age structure of catch
- Electronic dissemination of data
- Serves:
  - stock assessment
  - fishery monitoring
  - economic analysis

# Marine Recreational Information Program (MRIP)

- MRIP is replacing MRFSS to better serve today's management needs
- Recreational fishing effort and catch using:
  - Angler registry
  - Telephone surveys
  - Shoreside sampling surveys
- Based on a sample of all trips



# Fishery Observers

- NOAA Fisheries deploys fishery observers to collect catch and bycatch data from commercial fishing and processing vessels.
  - Annually 42 fisheries are monitored by observer programs logging over 60,000 observer days at sea.
  - NOAA Fisheries has been using observers to collect fisheries data from 1972 to the present.
  - Observers have monitored fishing activities on all US coasts, collecting data for a range of conservation and management issues.



# Abundance Index Fishery-Independent Surveys

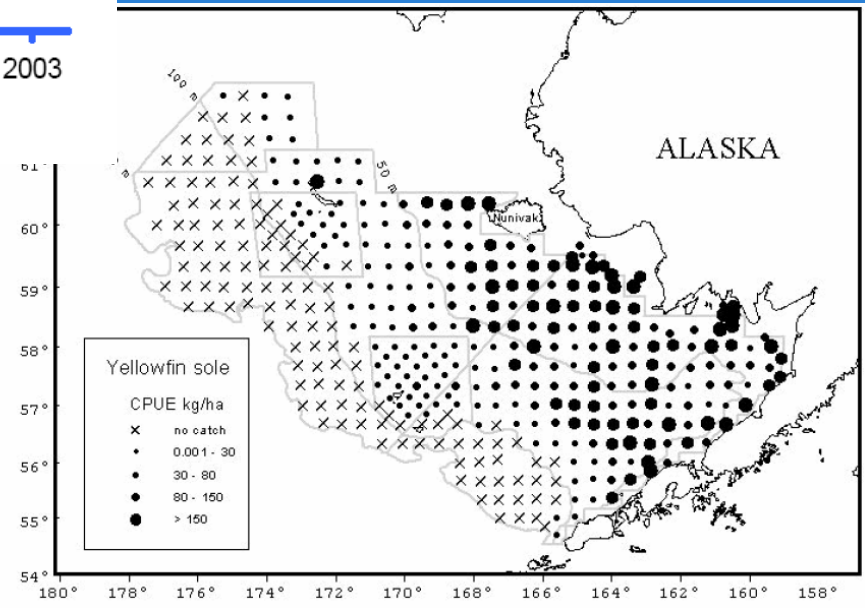
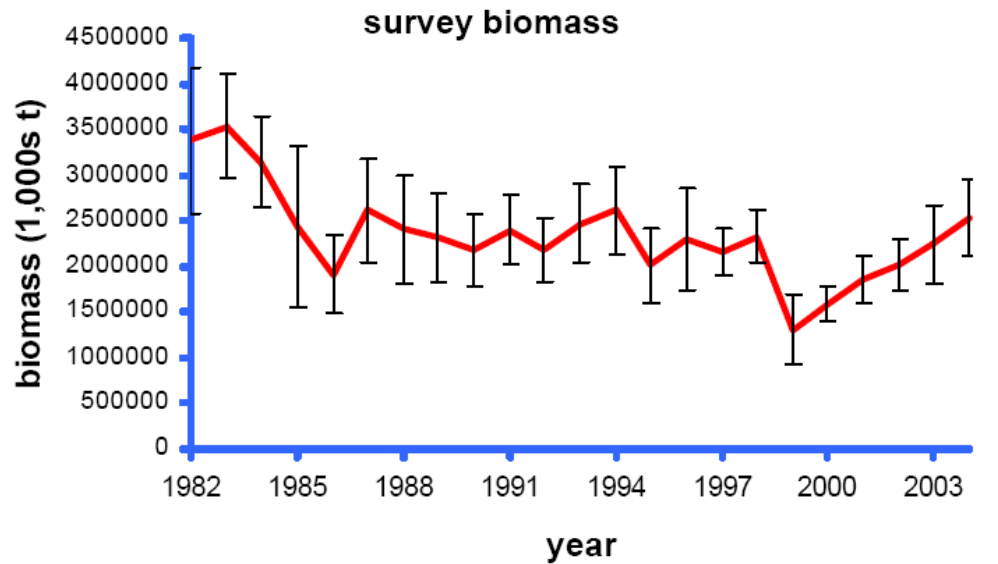


- Catch Rate =  $q \times \text{Abundance}$
- Key is stable  $q$  over many years
  - Sampling gear and protocol is highly standardized;
  - Sampling locations follows a statistical design



- Most survey methods produce relative time series, so information is only in the trend ( $q$  is constant, but scale is not important)
- Some methods (acoustics, visual, tag-recapture, some trawl surveys) can independently calibrate absolute  $q$  so each year's survey directly estimates abundance

# Bering Sea Multispecies Bottom Trawl Survey: yellowfin sole



# Fishery-Dependent Abundance Index

- Fishery Catch Rate (CPUE) should also follow relationship:
  - Catch Rate =  $q$  x Abundance
- But  $q$  may not be constant because:
  - Fishers don't spread their effort out in a statistical design over the range of the stock
  - Fishing technology changes over time
  - Statistical analysis can compensate for, but not eliminate, these shortcomings
- Degree of  $q$  stability: single FSV vs. multiple chartered vessels vs. fishery logbook data

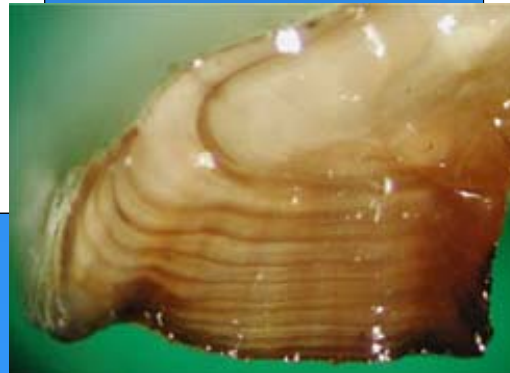
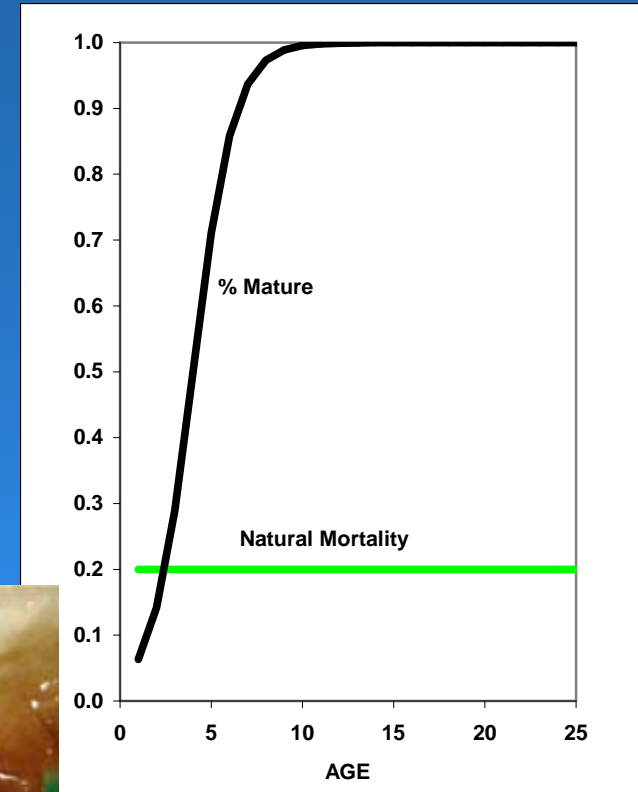
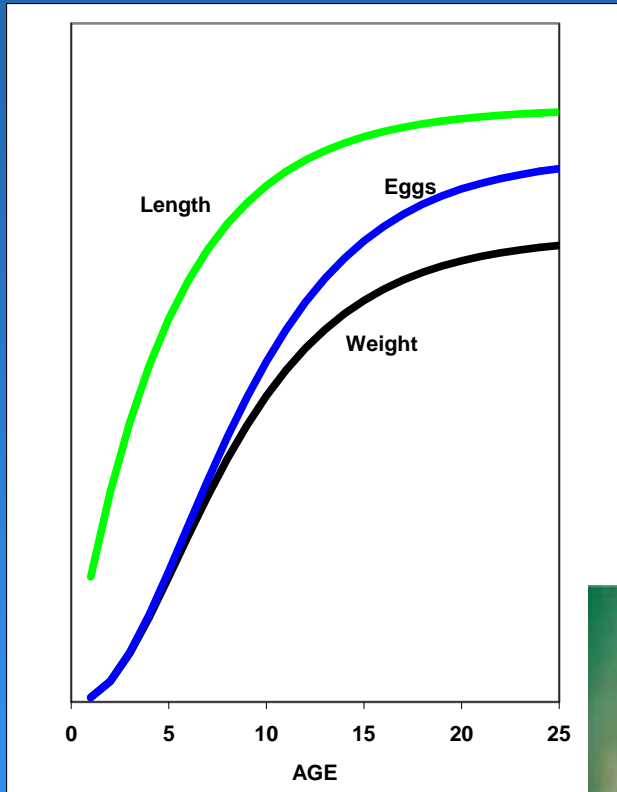


# Advanced Technology



- Autonomous Underwater Vehicle
- Can contain cameras, sensors, acoustics
- Reach into habitats inaccessible to other survey tools

# Fish Biology and Life History



Ease: Length > Weight > Maturity >> Age >> Eggs >>> Mortality

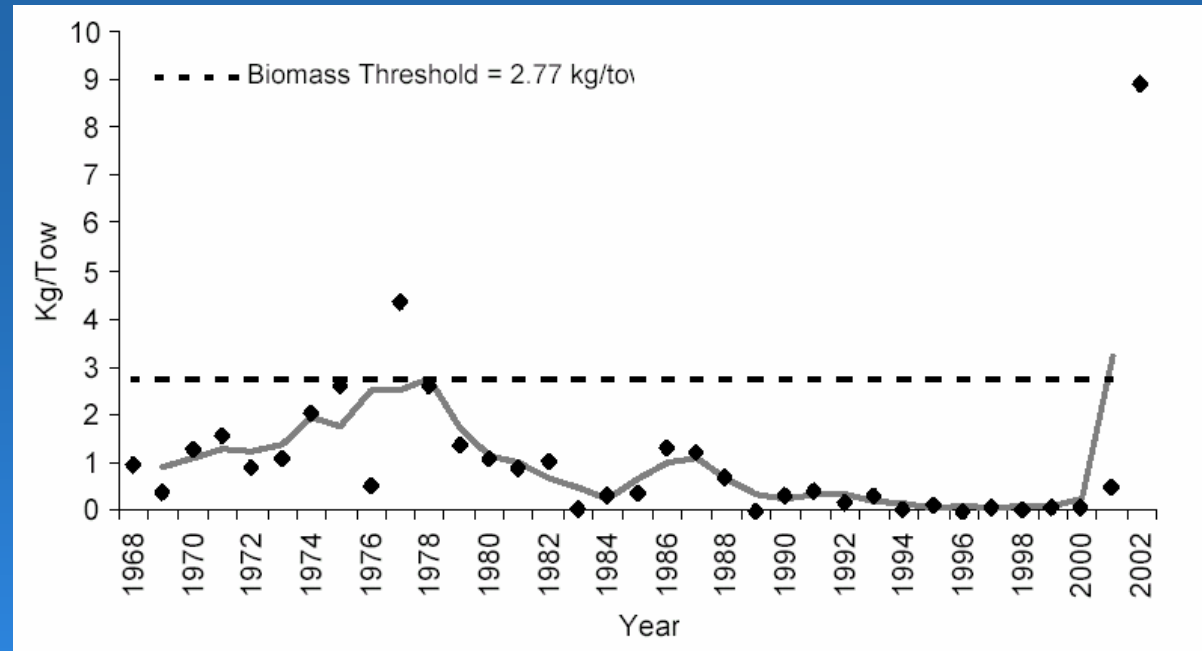
# Stock Assessment Methods

# Basic Assessment Approaches

- **Index Methods**
  - Is stock abundance:
    - Increasing, decreasing, or stable?
- **Equilibrium Methods**
  - On average, is fishing mortality:
    - too high, too low, or just right?
- **Dynamic Population Methods**
  - Measures stock abundance and mortality
  - Forecast stock abundance and catch level that maintains mortality target
- Choice depends on data availability and complexity of management questions



# Index Methods



- Running average of survey or fishery CPUE
- Compare to a benchmark level
- May also compute ratio of catch to index to get relative exploitation rate

# Index Methods: pros & cons

- Advantages:
  - Requires only an index of stock size and catch.
  - Able to detect substantial changes in stock size and exploitation.
- Disadvantages:
  - Imprecise (large sampling uncertainty)
  - Status can only be related to proxy reference points (e.g., historical averages).
  - Cannot reliably project stock size.
  - Difficult to provide objective management advice.

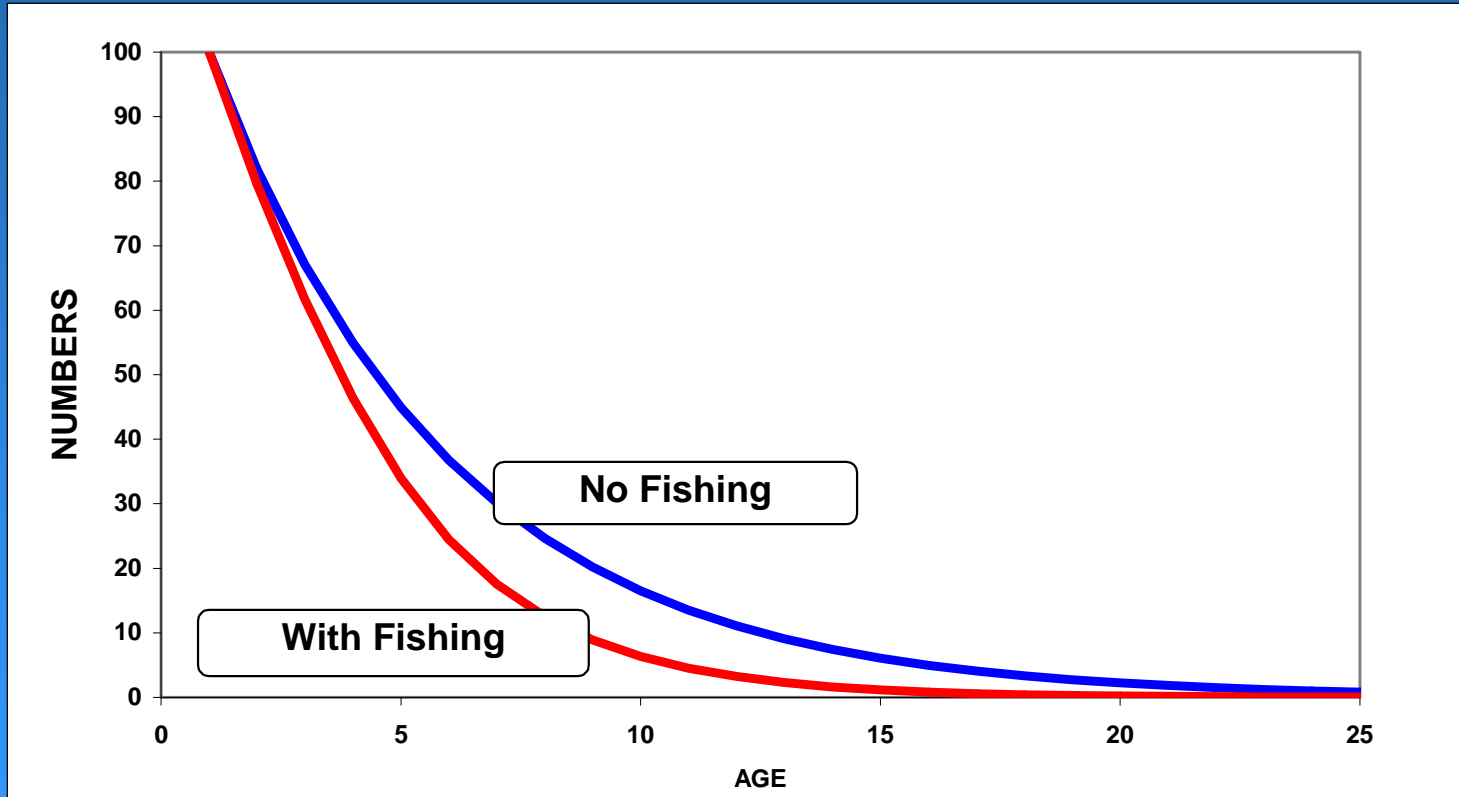
# Equilibrium Models Relate Fishing Rates to Effect On Egg Production

- Egg Production commonly indexed by Spawning Biomass
- Spawning Biomass Per Recruit is also known as:
  - SPR
  - Spawning potential ratio
  - Spawners per recruit
  - $F_{xx\%}$
- It is an index of the intensity of the effect of fishing on the reproductive potential of the stock

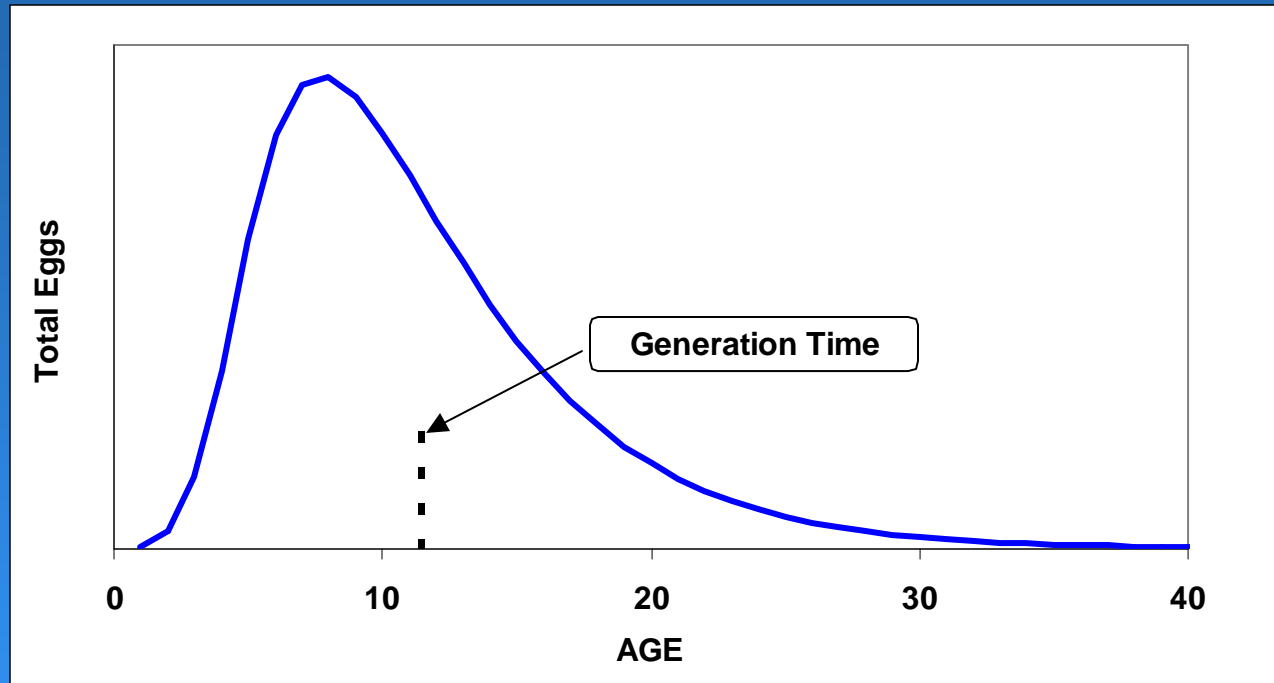
# Reproductive Potential

- Best: age-specific fecundity, including maternal effects on egg vitality
- OK: female spawning biomass or combined gender spawning biomass
- Weak: fishable biomass
- Complications:
  - Hermaphrodites
  - Density-dependent changes in life history over time

# Direct Fishing Effects on Numbers at Age

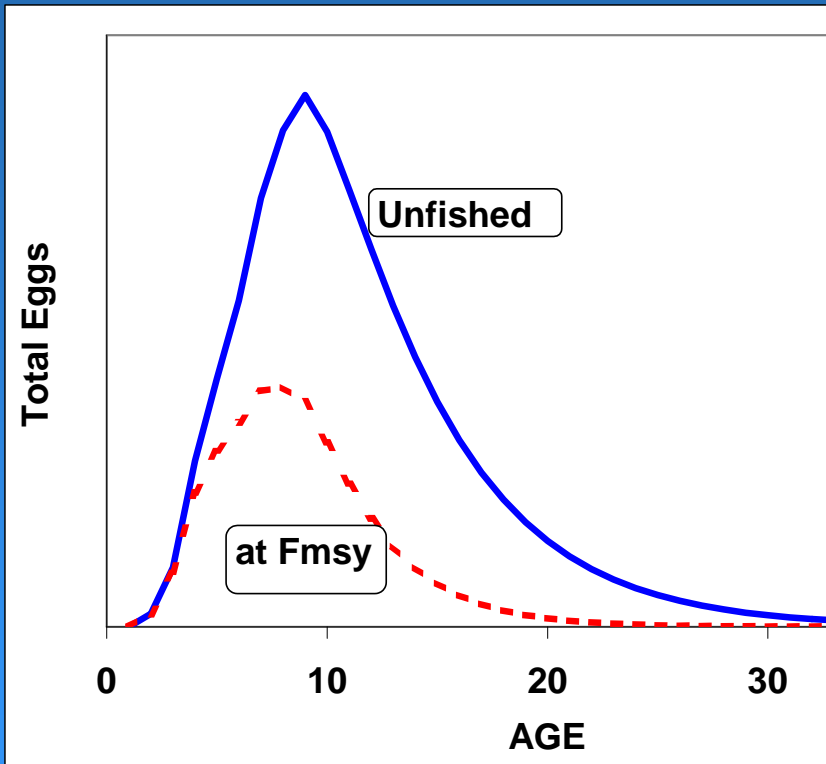


# Generation Time



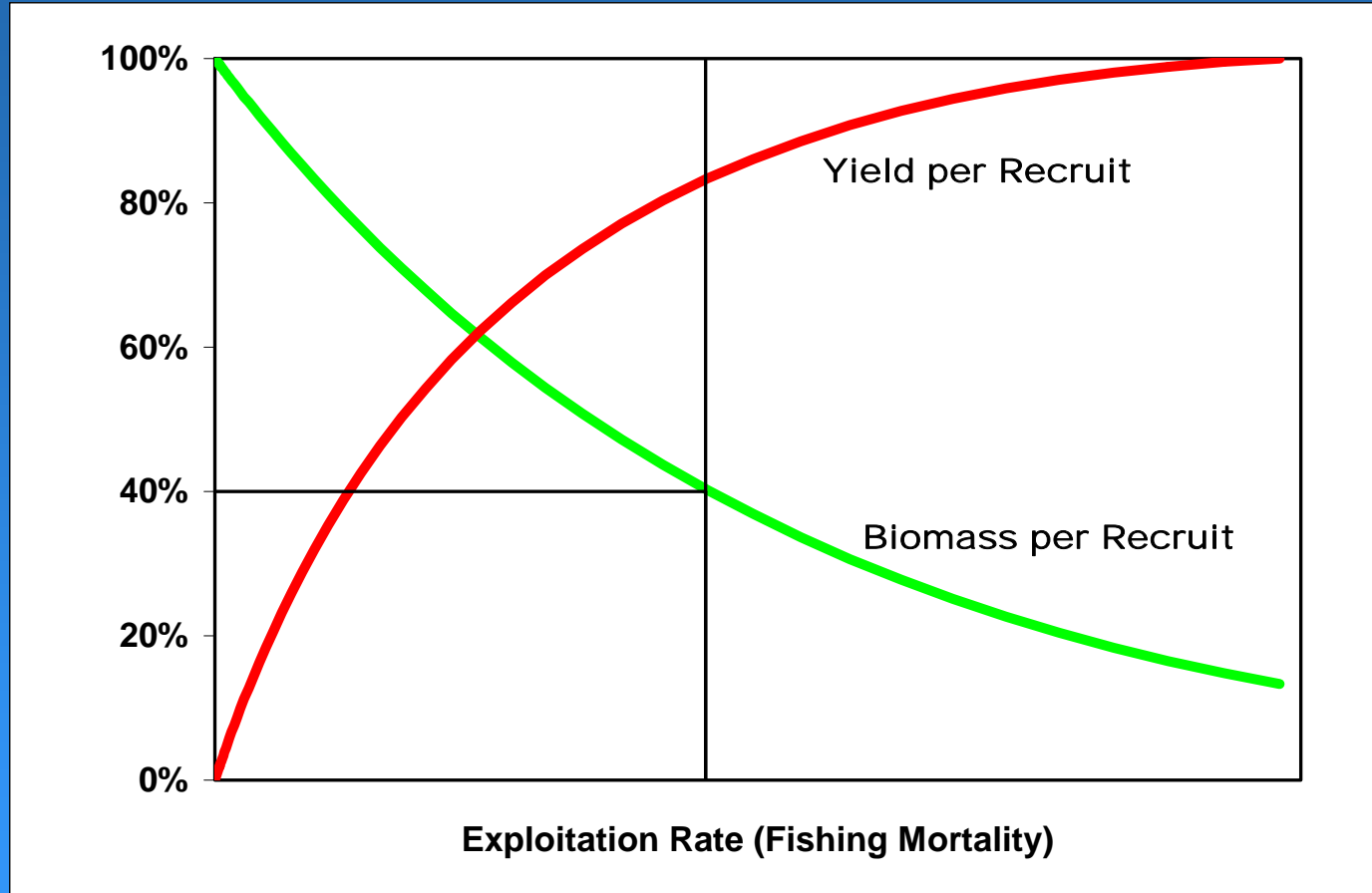
Weighted mean age of spawners; same as:  
Mean time from birth to production of offspring

# Fishing Reduces Mean Age



- Fewer old/large fish; some say “truncated”
- Smaller mean body size
- Shorter generation time
- Total stock dominated by younger fish, so fluctuates more with recruitment

# Fishing Effects on Yield and Eggs (Spawning Biomass) Per Recruit





# Equilibrium Methods: Pros & Cons

- Advantages:
  - Requires only age or size composition of catch
  - Provides direct information on relative fishing mortality level.
- Disadvantages:
  - Highly dependent on model assumptions
  - Status can only be related to proxy reference points
  - Cannot estimate or project abundance
  - Difficult to provide objective management advice.

# Dynamic Assessment Methods

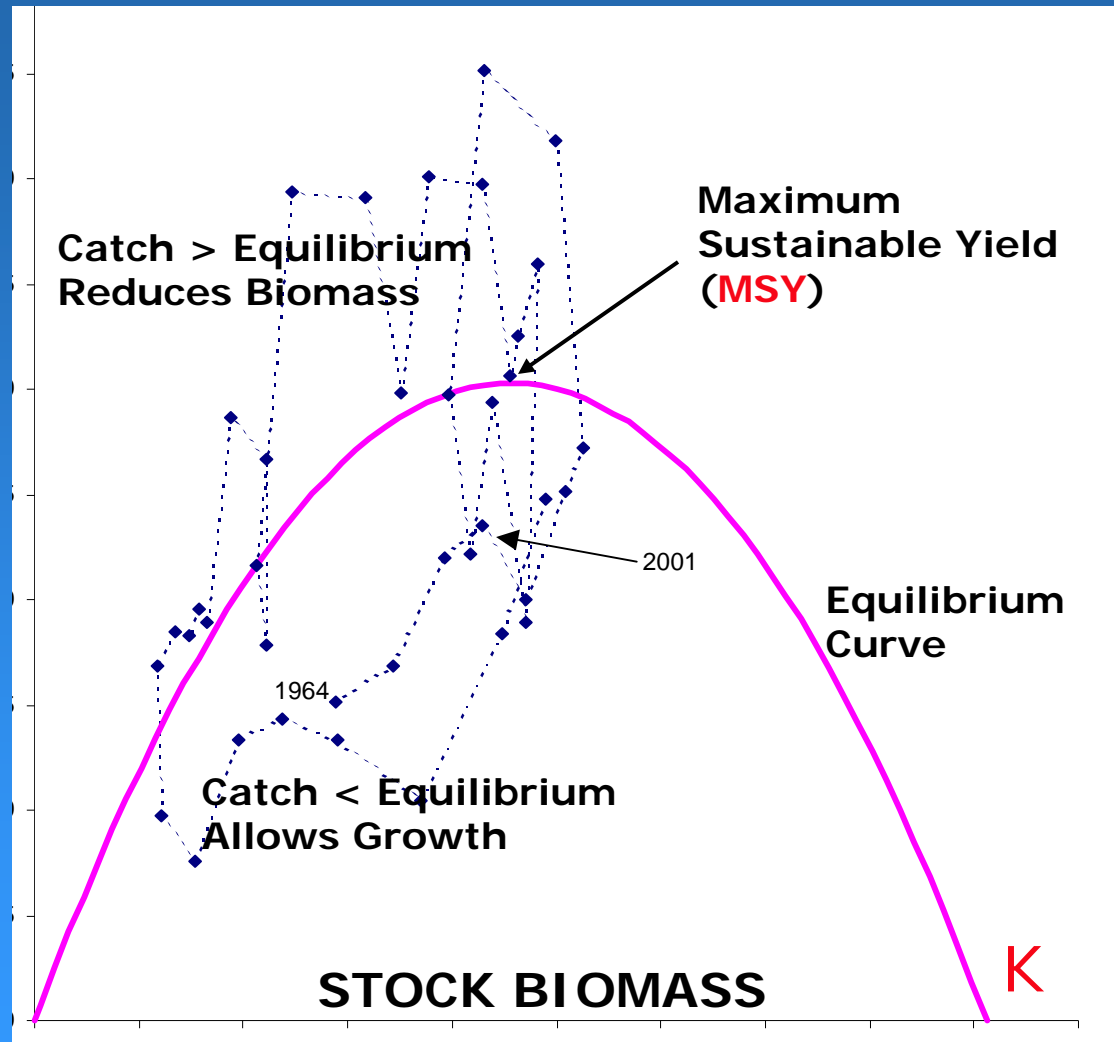
**Stock Net Production =**

**recruitment + growth - natural mortality - catch**

- **Recruitment:** production of eggs & larvae increases as spawner abundance increases, but their survival may decrease with crowding, cannibalism.
- **Growth:** body growth of individuals adds mass to the the entire stock, but slows as fish age, starve, crowd;
- **Natural Mortality (M):** background level due to predation, disease, etc.; link to ecosystem
- Production Models treat recruitment, growth, and natural mortality as a combined process because no data about the details

# Production Model

- Population increase is proportional to its biomass, but the rate of increase slows as the population approaches its carrying capacity (**K**).
- If removals can be replaced by stock production each year, on average, the fishery is sustainable.
- If stock size is maintained near half its carrying capacity, the population growth rate is fastest, and sustainable yield is greatest (**MSY**).



# Production Models

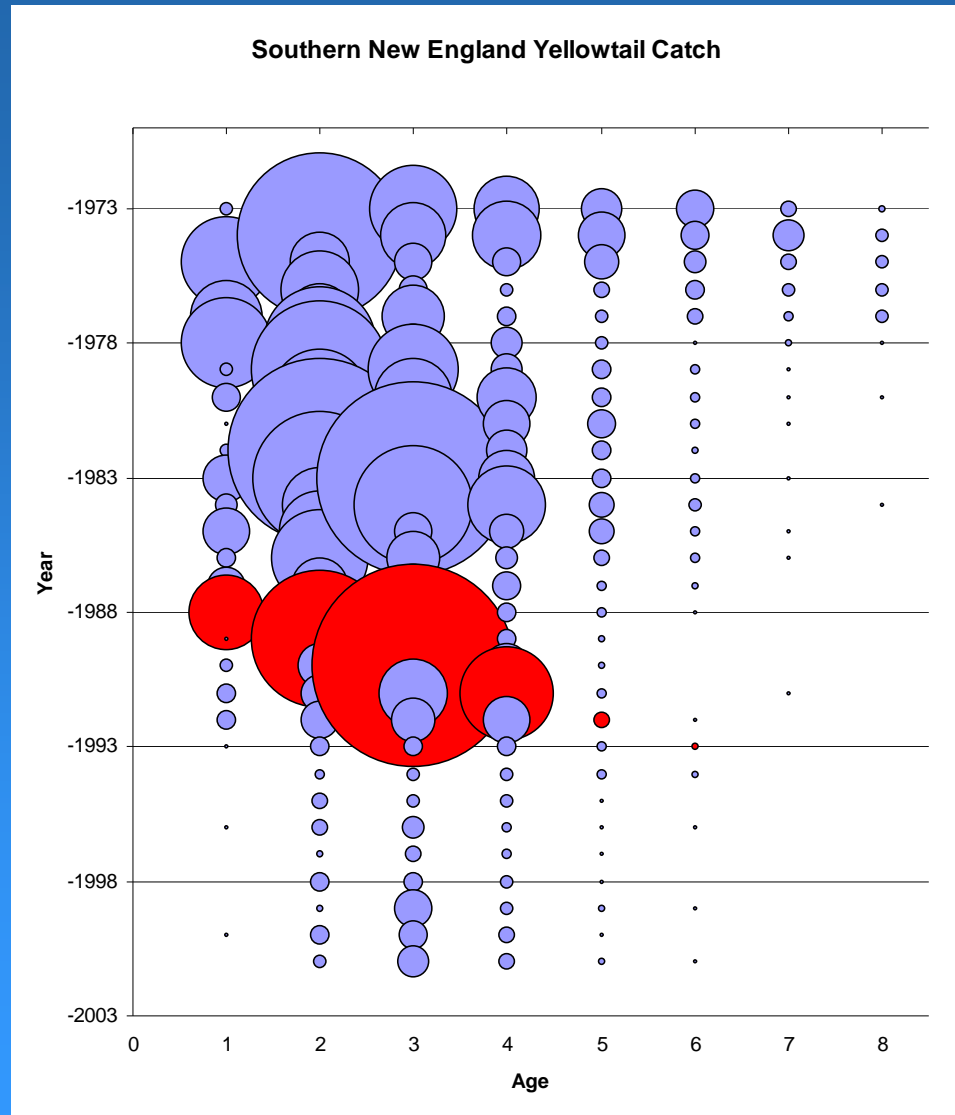
- Advantages:
  - Estimates abundance and mortality
  - Can do limited projections (forecasts)
  - Does not require intense catch sampling.
- Disadvantages:
  - Requires a long time series of accurate catch and reliable survey data - representing a wide range of stock and harvest conditions;
  - Not sensitive to demographic changes (e.g., recruitment events, truncated age structure, immature-mature components);
  - Scaling of absolute estimates may not be reliable because model is very simple;
  - Projections are simplistic (no information on incoming recruitment).

# Age-Based Dynamic Models

- Adding age data allows:
  - Estimating age-specific fishing mortality
  - Including details on demographics (e.g. age at maturity differs from age at entry to fishery)
  - Estimating year-to-year fluctuations in recruitment of young fish

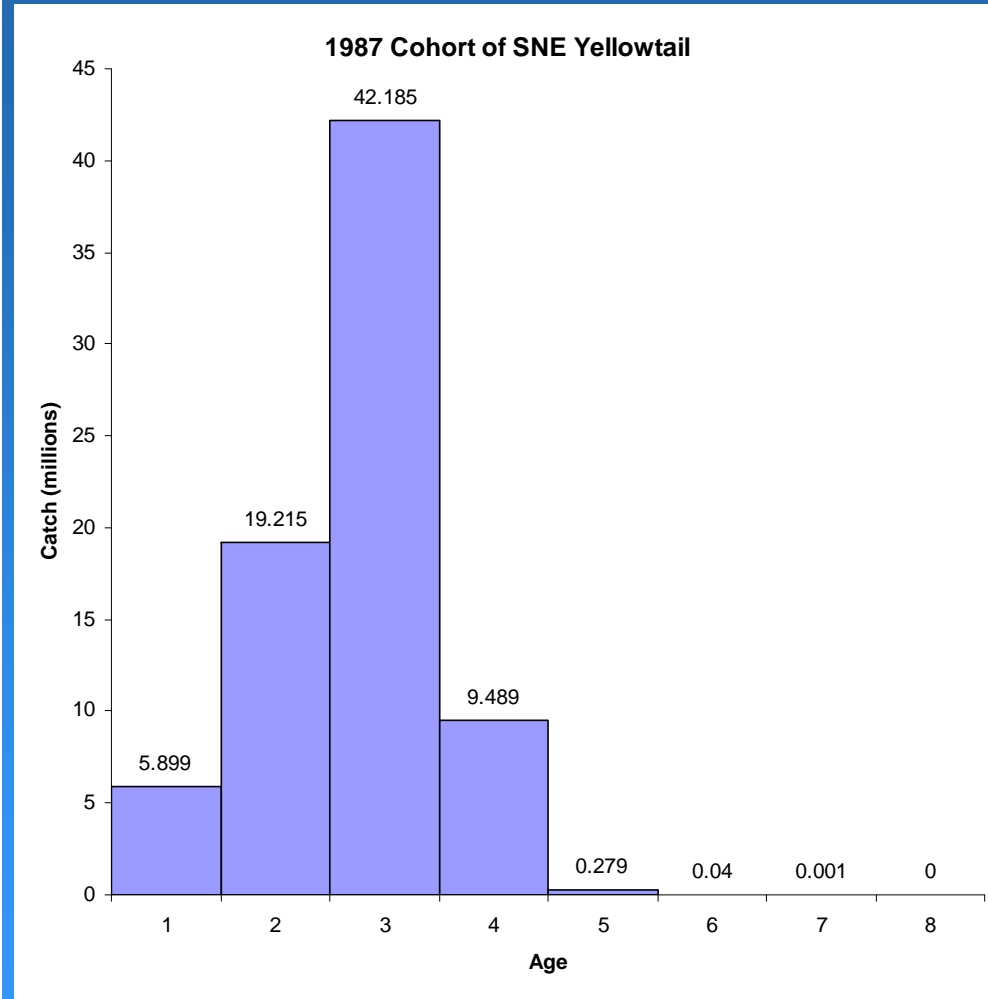
# Age-Based Methods

- Age distribution of the catch estimated from census of total catch biomass and port samples.
- Example:
  - F on age 1 declined after 1989
  - Survival to older ages has declined
  - 1987 yearclass dominated the catch in the late 80s early 90s.



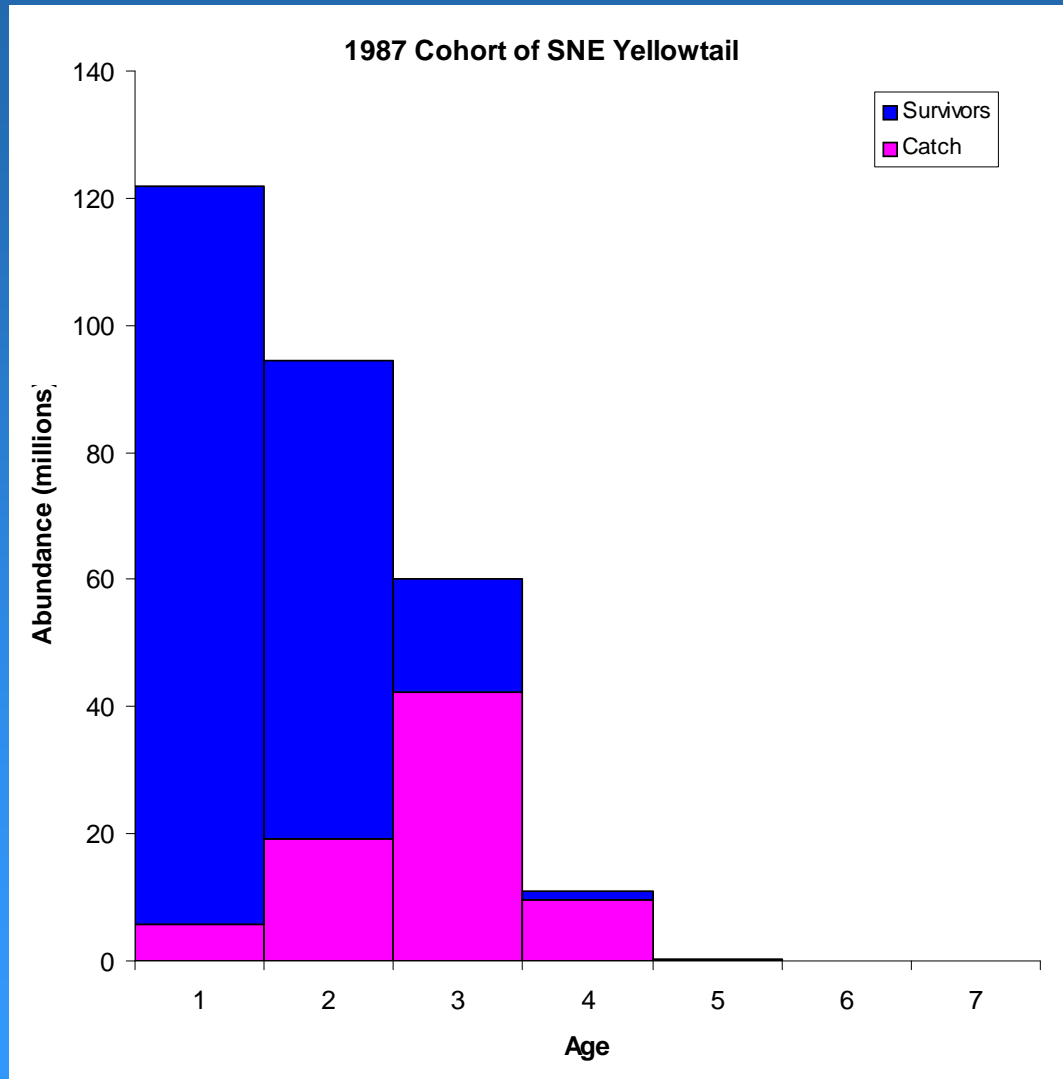
# Virtual Population Analysis

- Over the lifespan of the 1987 yearclass, 77 million fish were caught.
- We also know that some fish died from natural mortality.
- So, *at a minimum*, there were 77 million fish when they were 1 year olds.
- But this is just the population we “saw” (*the virtual population*) from the underlying true population.
- *VPA* reconstructs the true population from the virtual population.



# Virtual Population Analysis

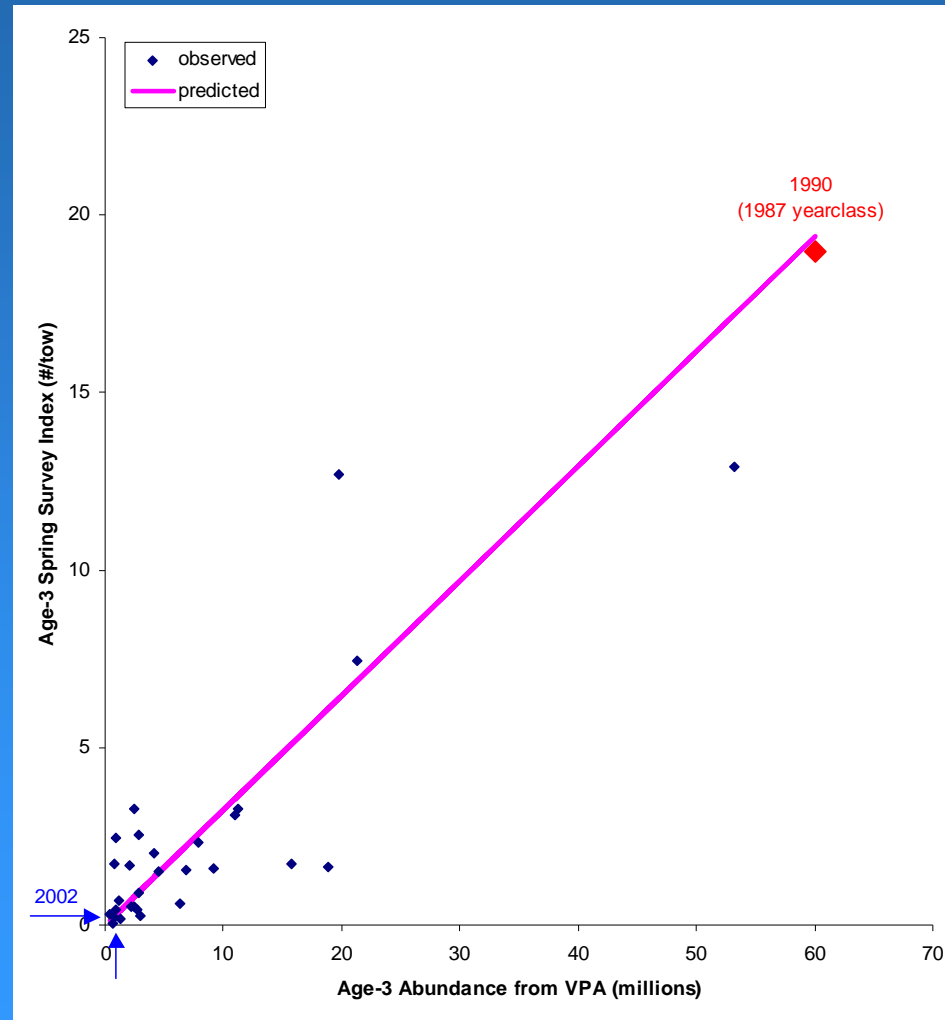
- By accounting for observed catch over the lifetime of the cohort (77 million) and natural mortality,
- the age-1 abundance estimate is 122 million.





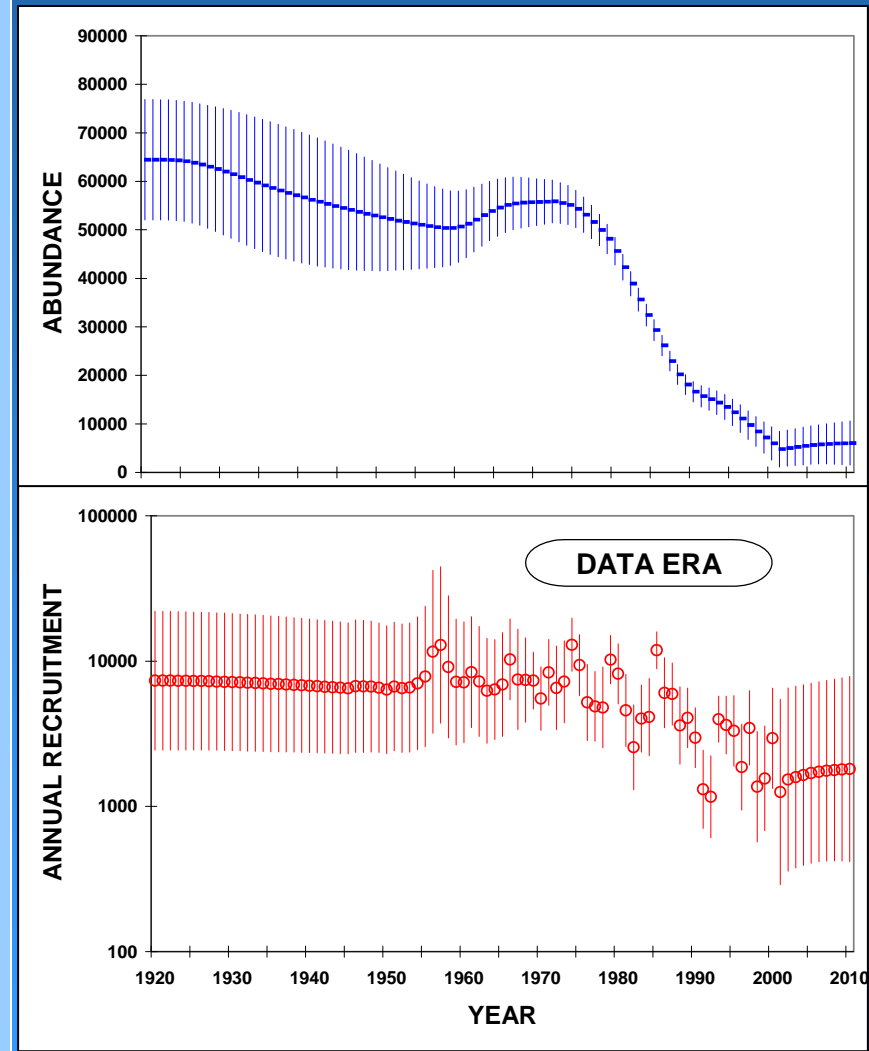
# VPA Calibration

- VPA is calibrated by adjusting parameters of the model to produce a good match to abundance estimated from surveys



# Integrated Analysis

- Age-based internal model, but rather than work backwards with each virtual cohort, it works forward as a simulation
- Able to use various age, length, abundance data to calibrate model
- Better able to deal with missing data and balance lack of fit across all available data
- Produces comprehensive estimates of model uncertainty
- Smoothly transitions from pre-data era, to data-rich era, to forecast within a single model



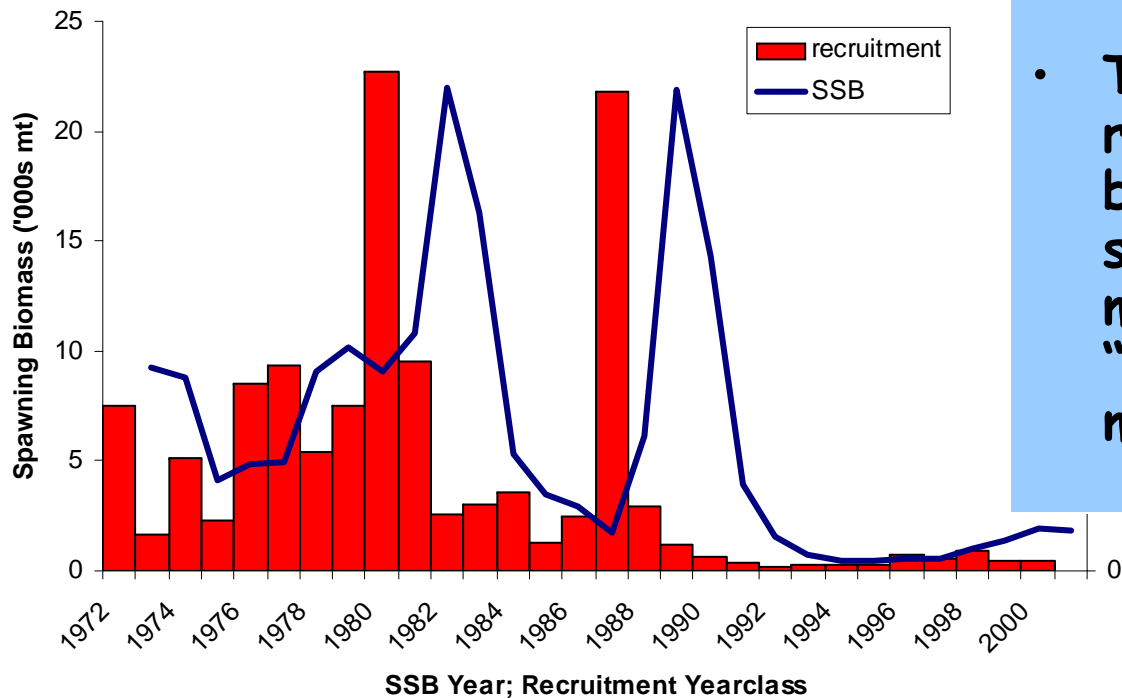
# Age-Based Assessments

- Advantages:
  - detailed information about the population (recruitment, age structure, mortality)
  - Age-structure allows non-equilibrium forecasts
- Disadvantages:
  - More complicated to use
  - requires more data, particularly accurate catch at age
  - may be a limited time series for VPA type models
  - Integrated Analysis can be best mix of Production model and age-structured model

# Data, Model Choice, Outputs

- Index Method: relative biomass trend only, no  $F$  estimate
- Equilibrium Method: average  $F$  only, no trend and no biomass
- Dynamic Methods: produces trend and absolute level of biomass and  $F$ , adding age data provides more detailed tracking of stock and forecasting of changes

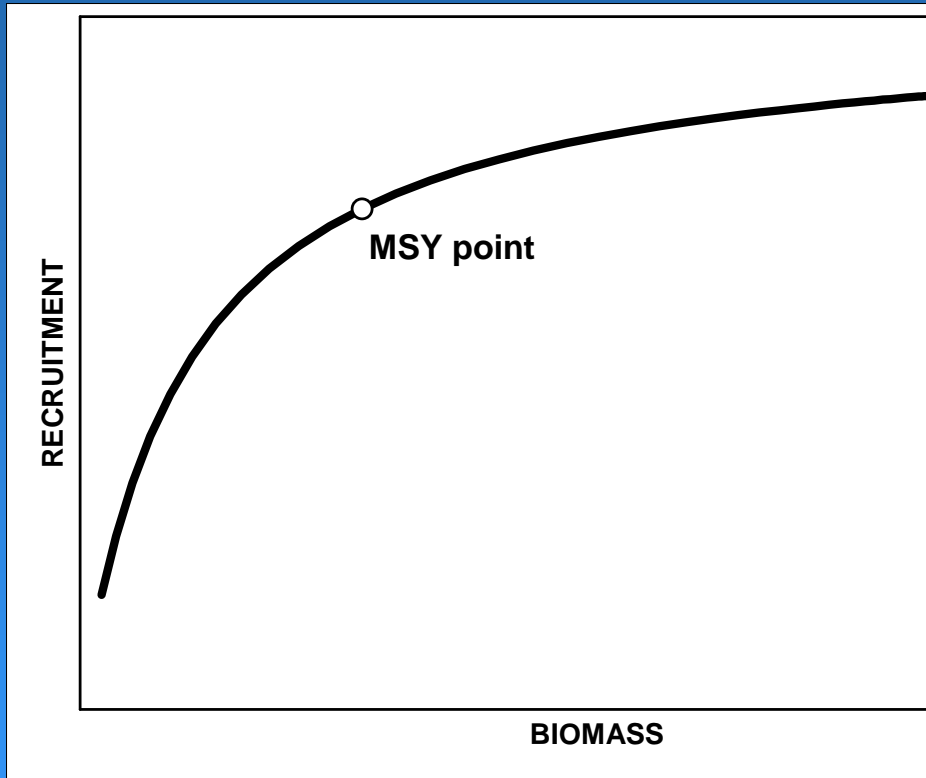
# Age-Based Assessment Results



- Annual estimates:
  - stock size (SSB)
  - Fishing mortality
  - Recruitment
- Time series of recruitment and spawning biomass allows a look at stock productivity that is more detailed than the "black box" production model

# Stock Productivity & Fishery Control Rules

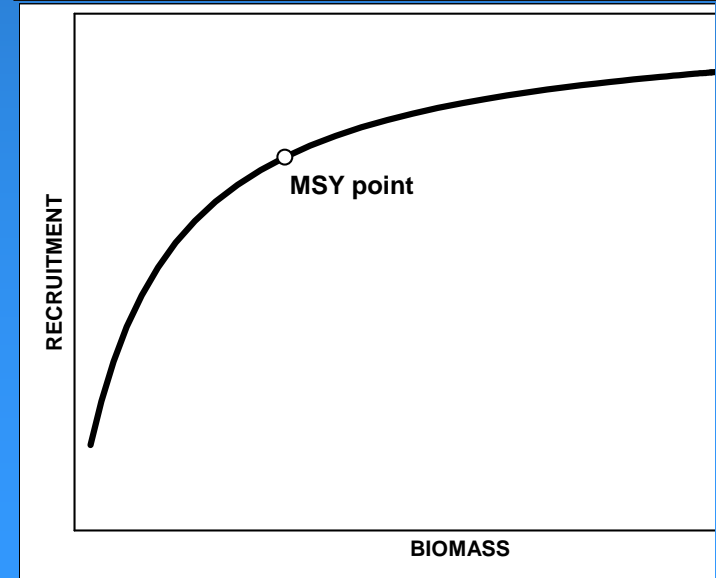
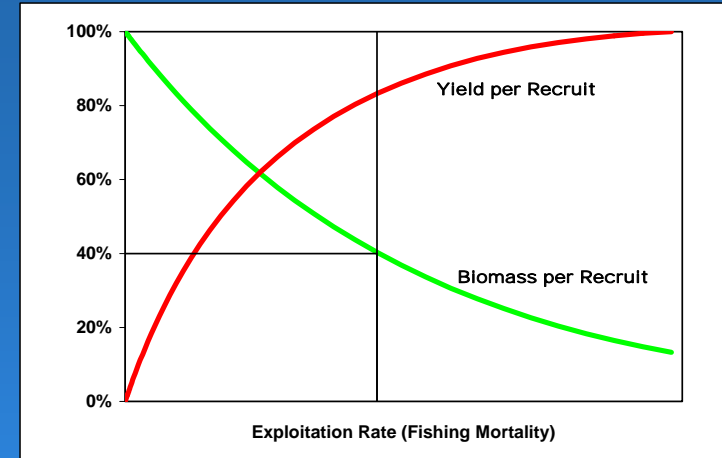
# Spawner-Recruitment



- Beverton-Holt curve shown; other shapes possible
- Stocks with high productivity/resilience keeps  $R$  high as  $B$  declines, but no spontaneous generation!
- Environment causes year-to-year deviations from this average curve, sometimes extreme and with trends
- Long-term climate pattern and ecosystem shifts can change the curve

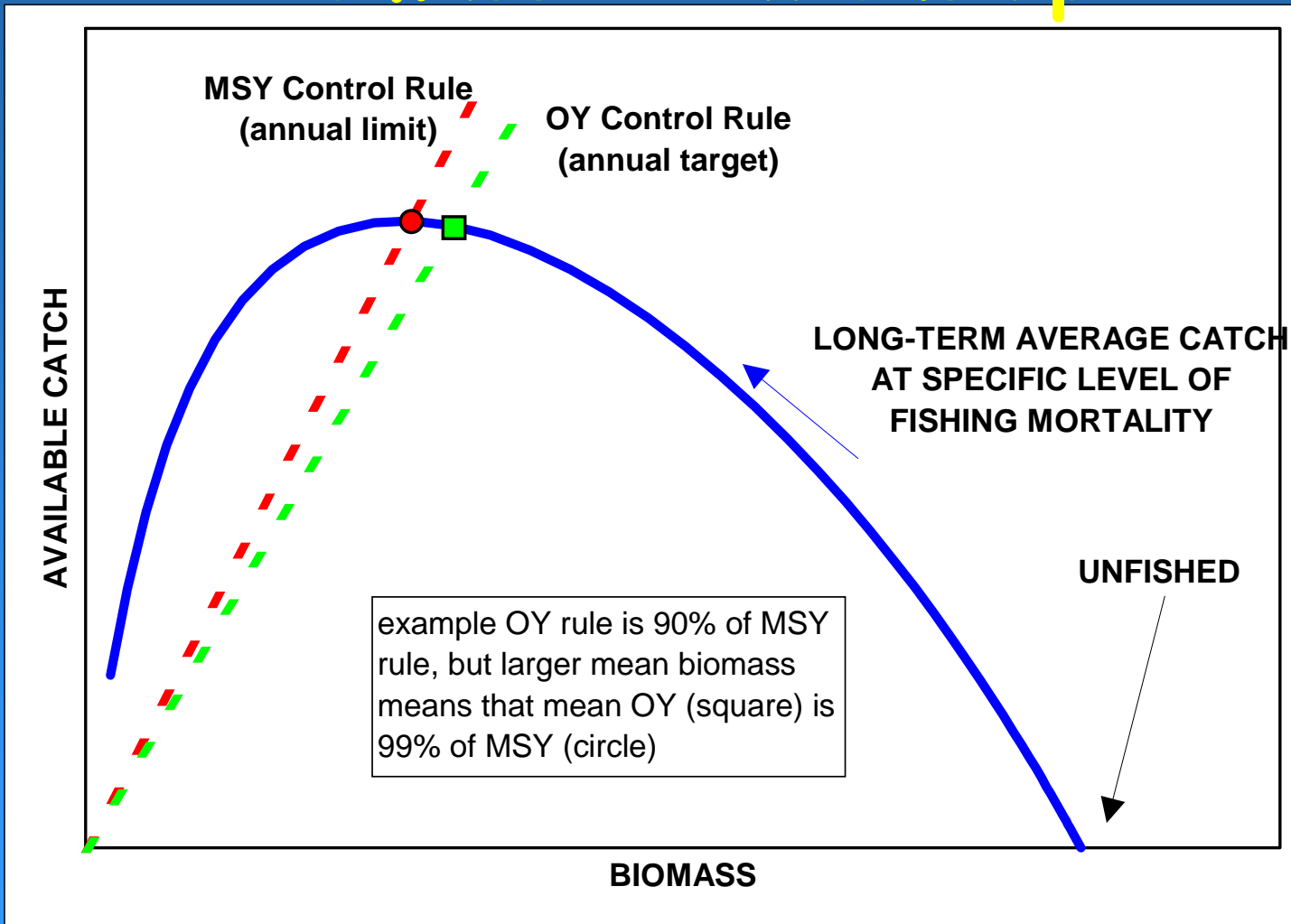
# Combine Spawner-Recruitment And Direct Fishing Effects

- Direct Fishing effect:
  - Increases catch per recruit (until growth overfishing)
  - Decreases biomass per recruit
- Spawner-Recruitment effect:
  - Decreases recruitment when biomass is reduced
- Combining the two effects:
  - Produces dome-shaped catch vs. biomass curve
  - Basis for MSY calculations



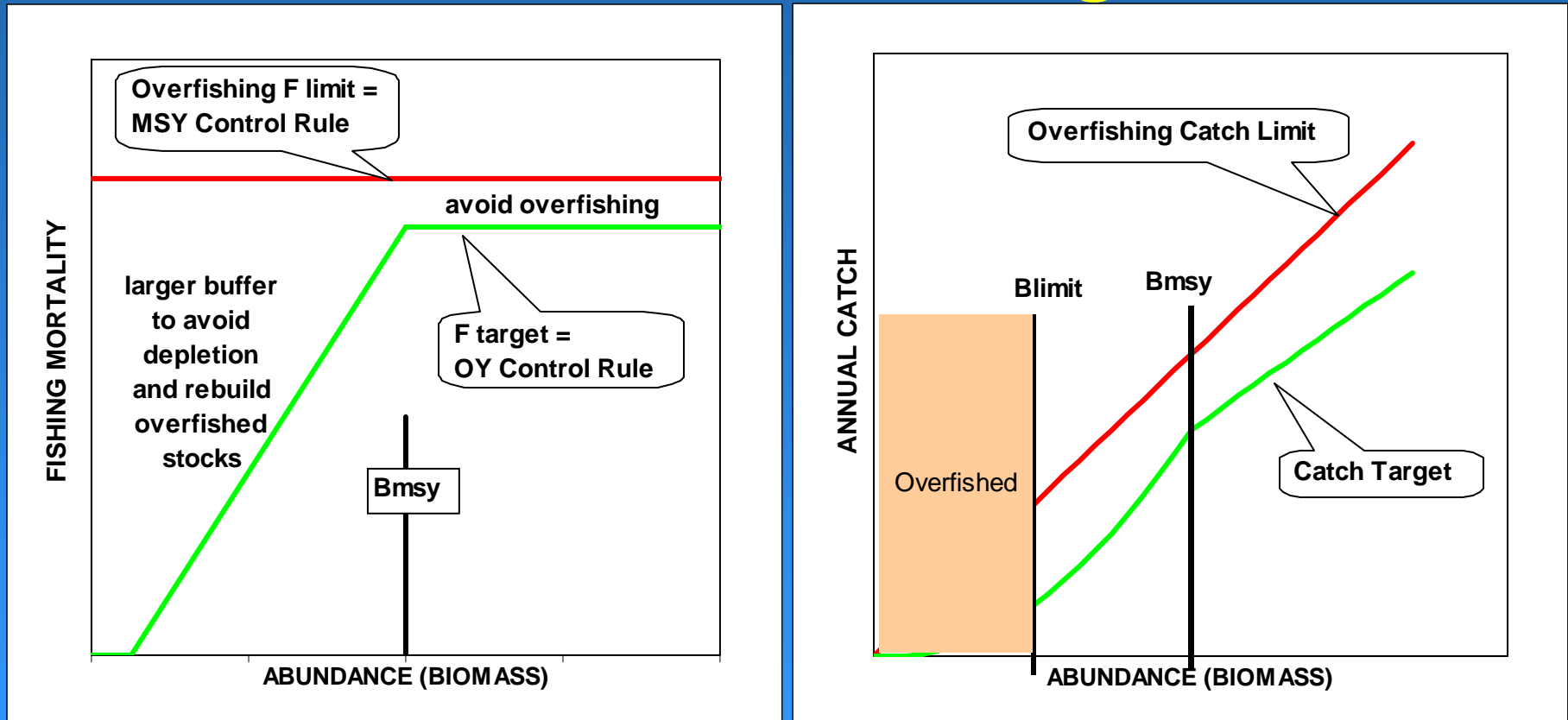


# MSY and Dome-Shaped Catch-Biomass Relationship

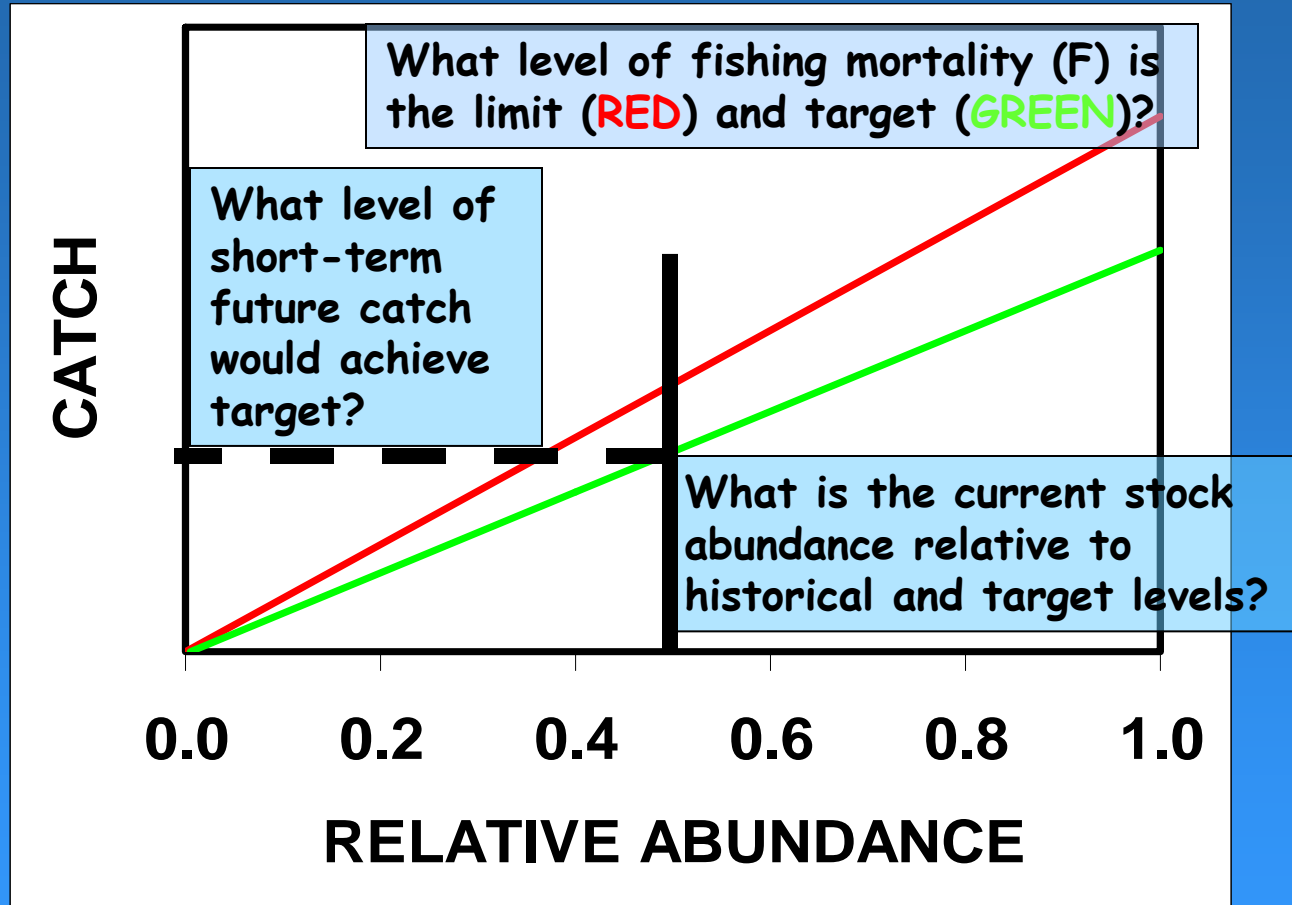


\*asymmetric curve due to spawner-recruitment model, rather than simple production model

# Control Rule Calculates Catch Limit and Target

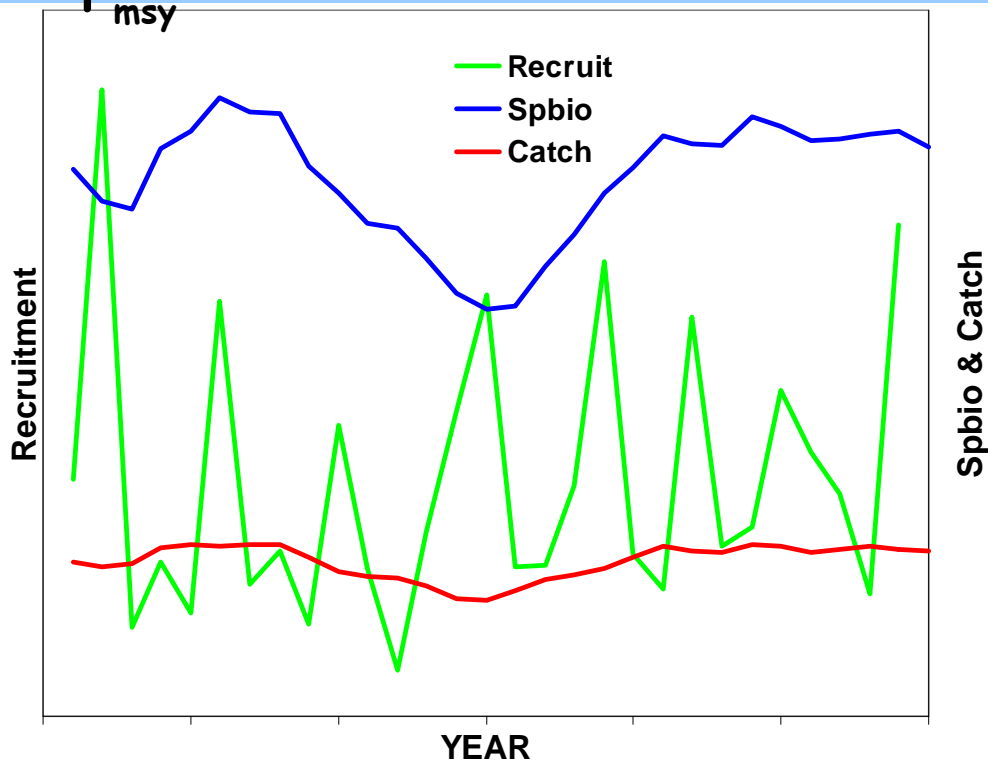


# Using Control Rule



# Dynamic MSY from Control Rule

- $F_{msy}$ : Fishing mortality that yields maximum average yield over the long term
- MSY is then the long-term result of fishing at  $F_{msy}$
- $B_{msy}$  the average stock biomass that results from fishing at  $F_{msy}$

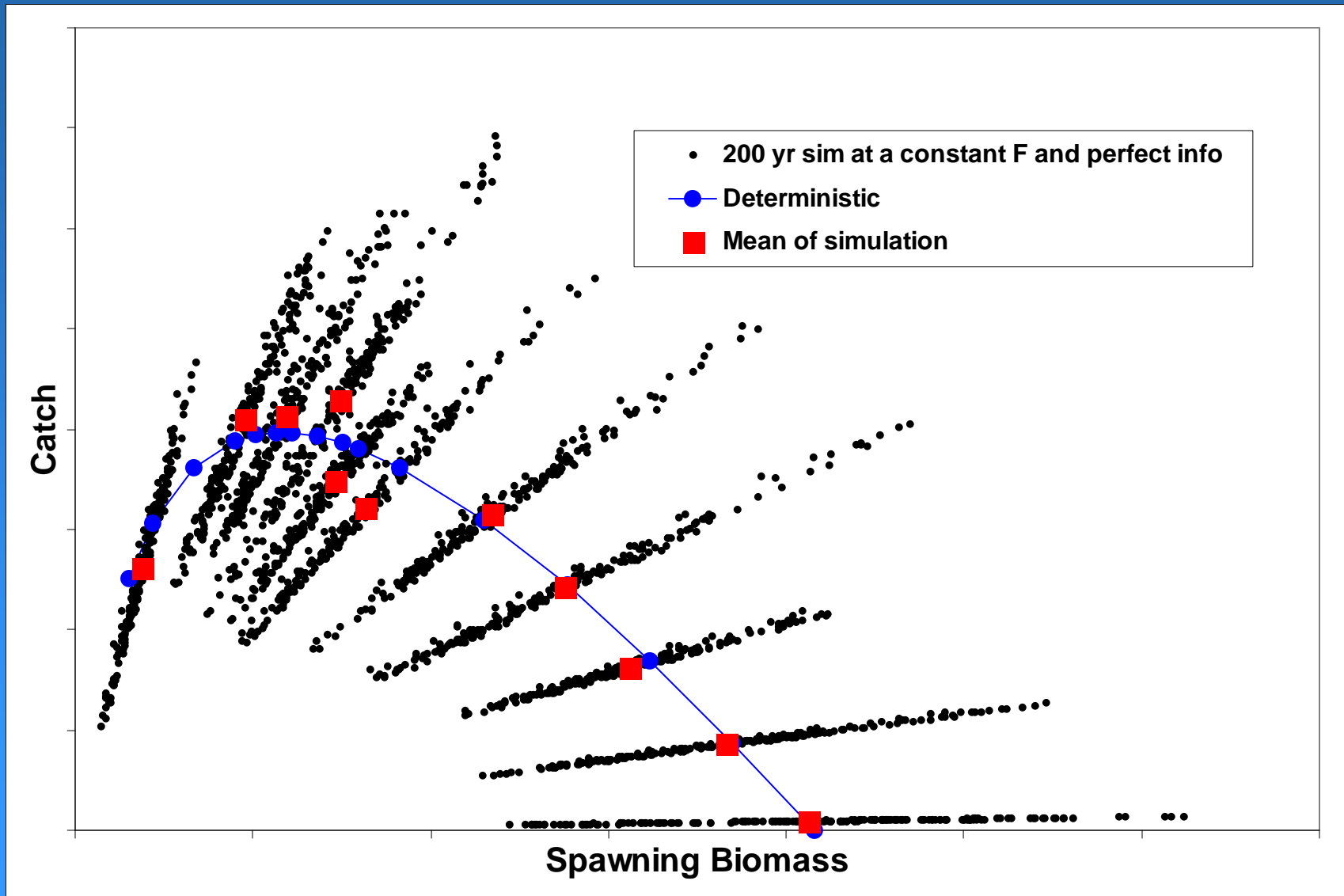


To keep  $F$  constant, fishery managers need to:

forecast the biomass next year to adjust the Quota, or

have good control on the effective fishing effort so that the fishing mortality stays constant, even as stock abundance changes.

# Dynamic MSY: What If Projections



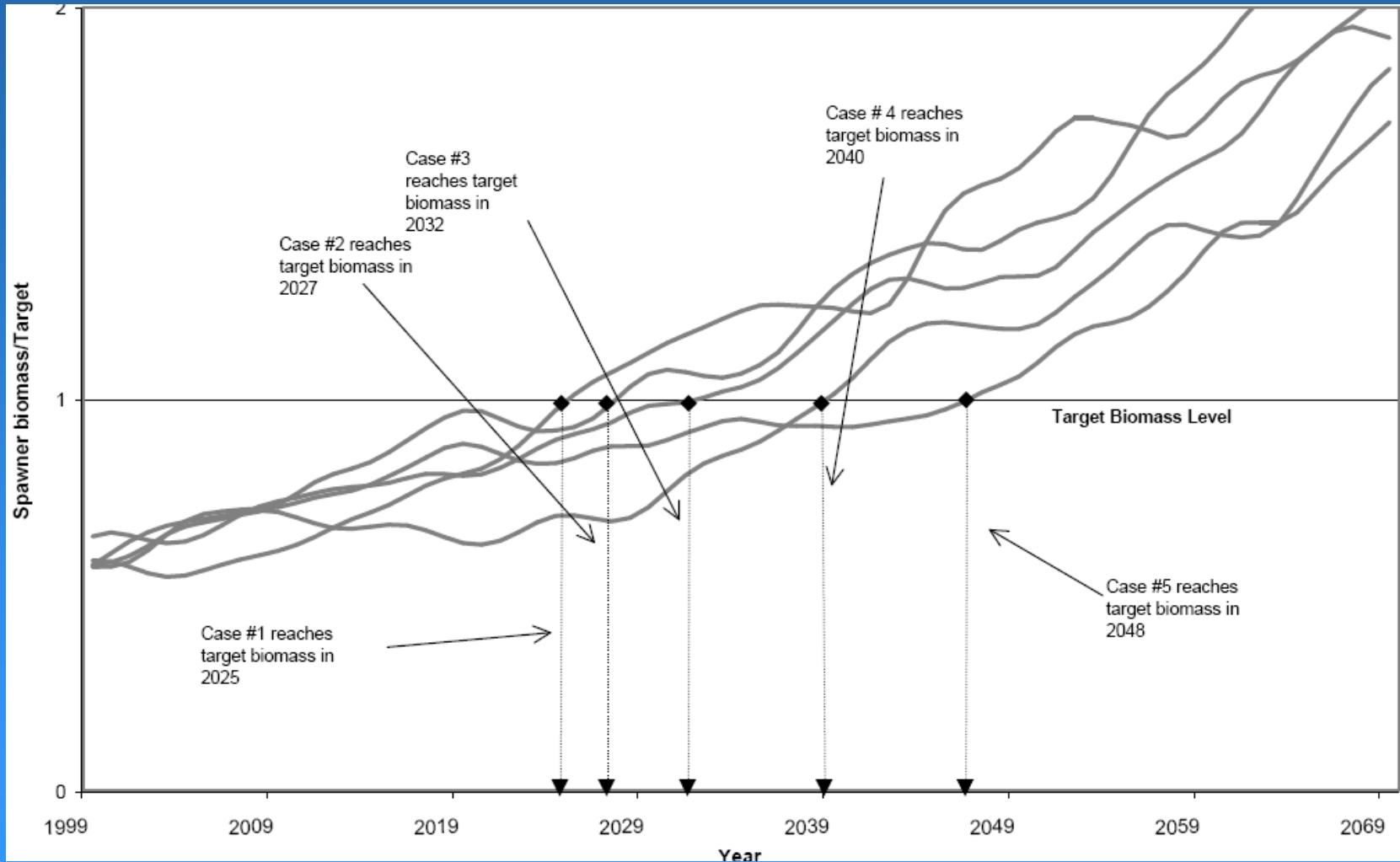
# Management Strategy Evaluation (MSE)



- Computer-intensive test of assessment and management performance
  - Simulate biology of stock
  - Generate estimate of index, including variability
  - Calculate management reaction to index (control rule), including time lags
  - Calculate response of stock to management
  - Repeat many times
- What kinds of index work best?
- What kinds of control rules work best?

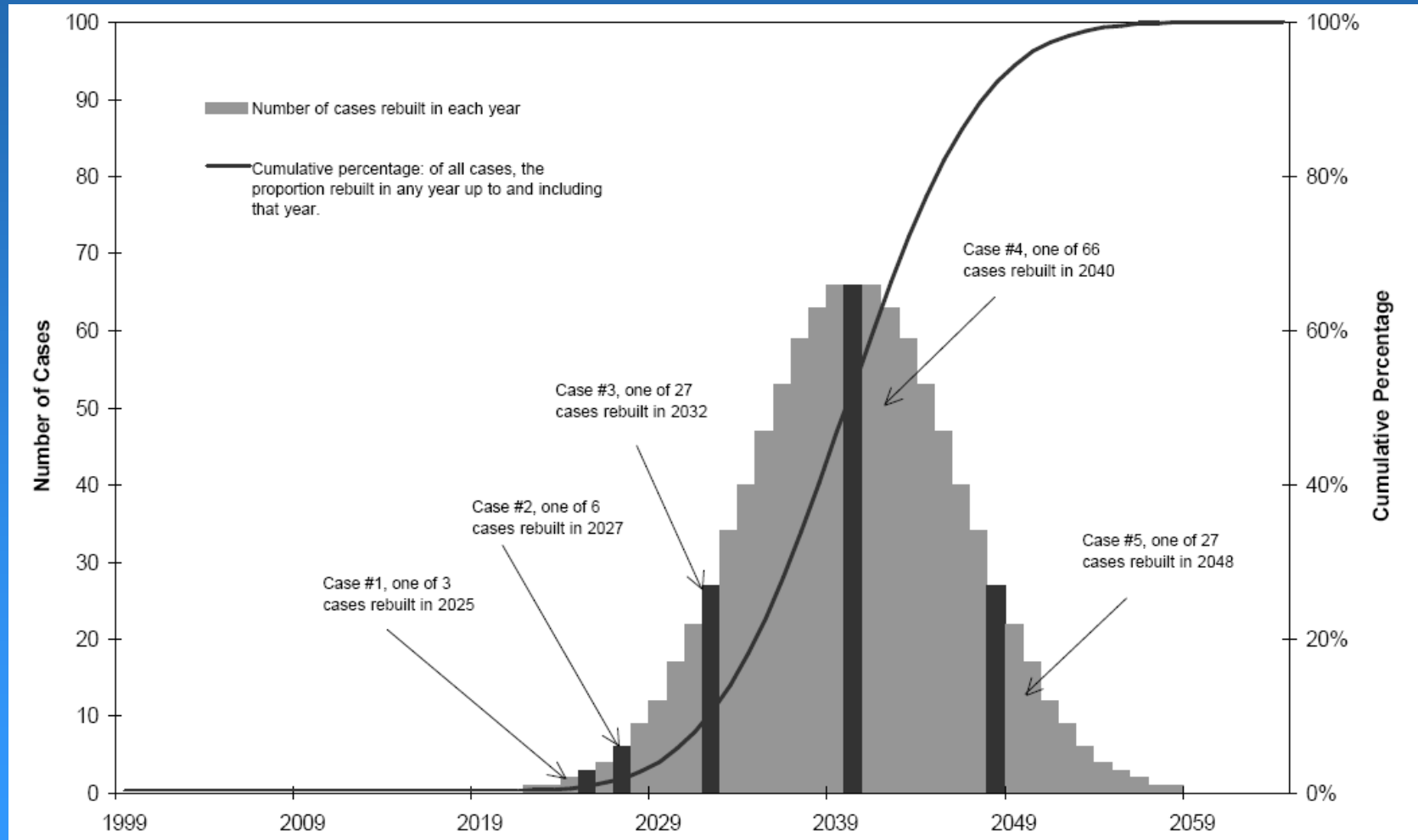
# Rebuilding Analyses

# Rebuilding Projections Based on Probability Distribution of Forecasts



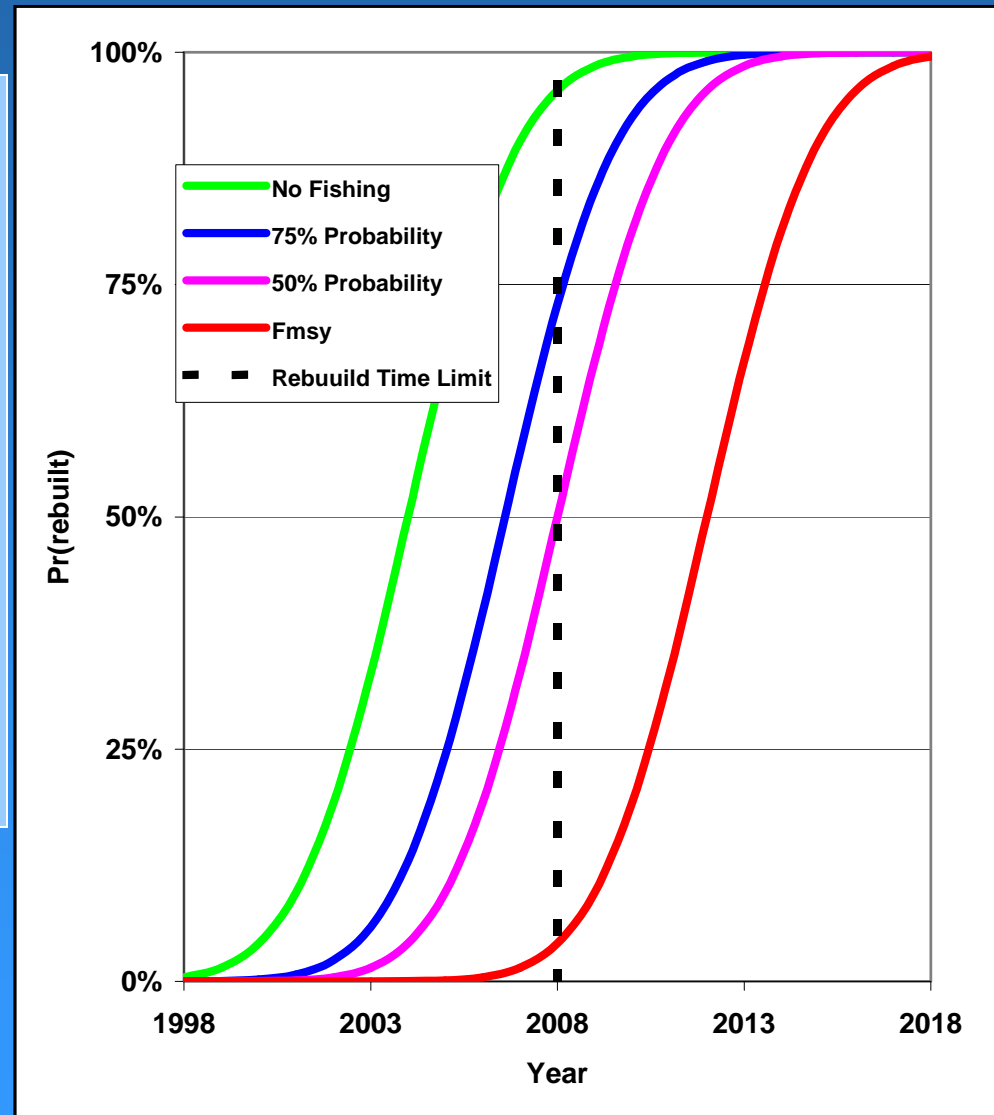


# Probability Distribution for Rebuilding



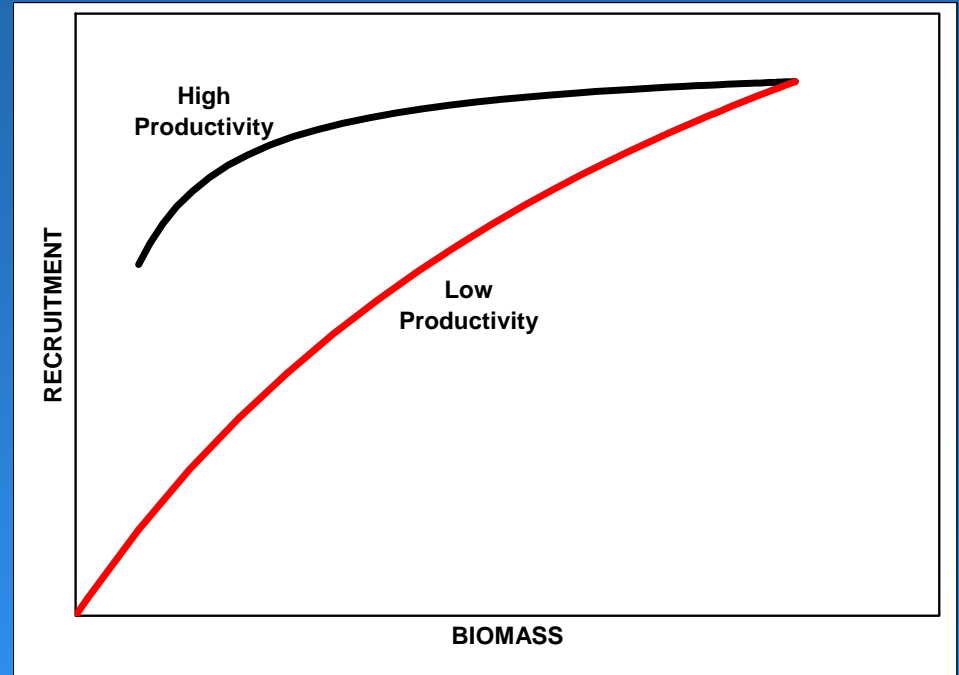
# Rebuilding Analysis

- For previously overfished stocks now on rebuilding plans, we typically calculate the sequence of future catches that will have an acceptable probability of allowing the stock to rebuild to its target level while taking into account various components of uncertainty



# Rebuilding Time Depends on Stock Productivity

High productivity stocks maintain high recruitment levels even as stock abundance declines (e.g. some New England groundfish). They rebuild quickly as fishing mortality is reduced.



Low productivity stocks can sustain only low fishing mortality rates and, if severely depleted, require multiple generations to rebuild even with minimal fishing mortality (e.g. west coast groundfish).

# Risk Assessment

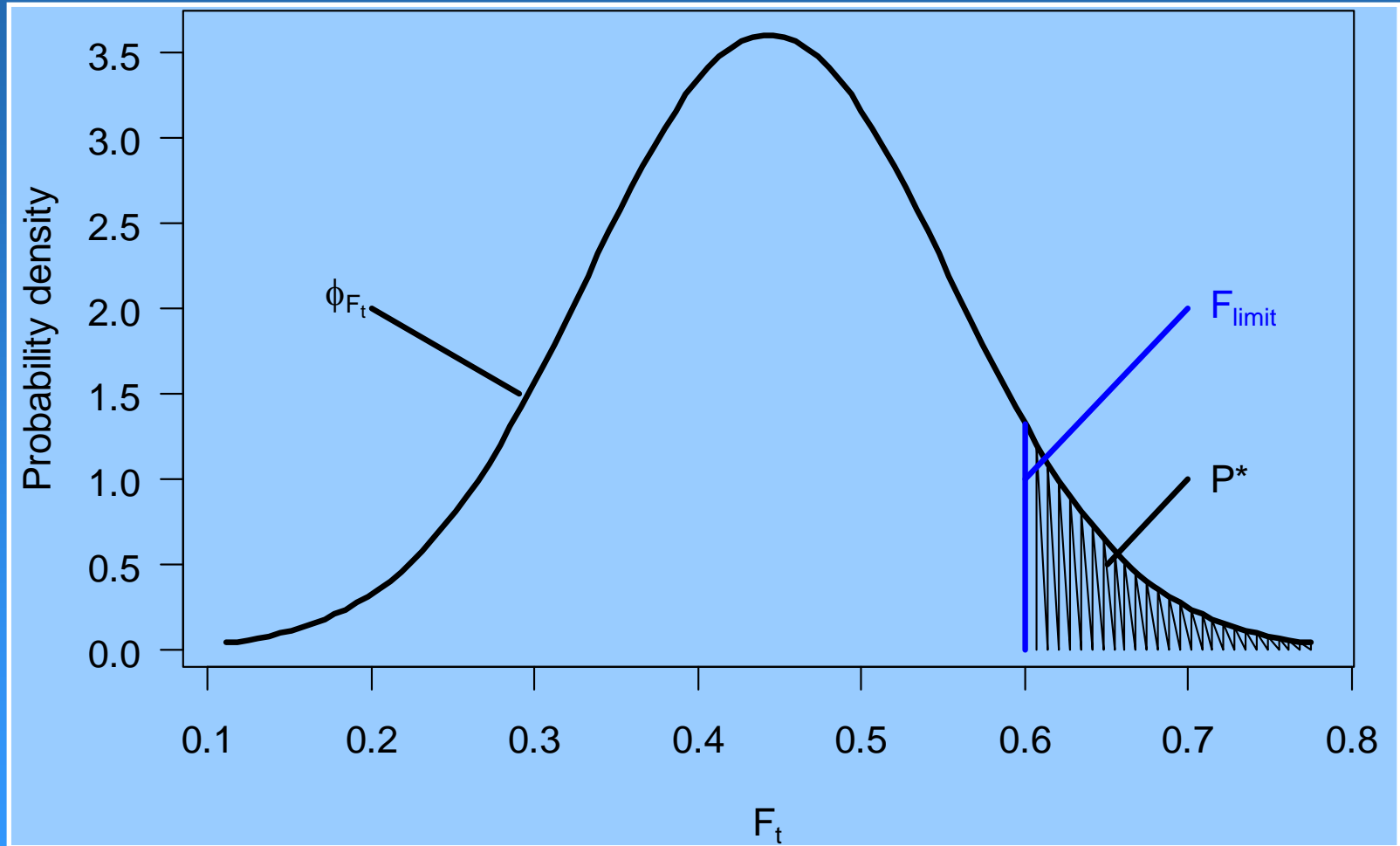
# ACL and Risk Assessment

- A comparably complete approach for setting ACLs would ask the question: What target harvest policy (e.g. ACLs) would:
  - Have no more than a **Y**% chance of exceeding the true overfishing level in each of the next several years;
  - Have at least a **X**% of leaving the stock above the target level of abundance some specified year into the future;
  - Produce **Z** level of catch and benefits

# Allowable Risk

- Any amount of fishing has an associated risk of overfishing ( $F > F_{\text{limit}}$ )
- Goal is not to minimize risk ( $F=0$ , risk=0), but to manage the stock at an acceptable level of risk
- Define  $P^*$  as the probability  $F_t > F_{\text{limit}}$
- Smaller  $P^*$  provides larger buffer against overfishing
- Scientists can do the calculation, but Value of  $P^*$  is a management decision

# Probability that $F$ exceeds a fixed limit



# Stock Assessment Limitations

- With accurate total catch, survey trend in abundance, and biological data, assessments can estimate stock status
- Missing, Variable and Biased data affect results
- Many factors held constant:
  - natural mortality, growth, productivity
  - Overall results appear more precise than they really are, especially with simple models
- Influence of non-fishery changes are mostly outside of knowledge base and models

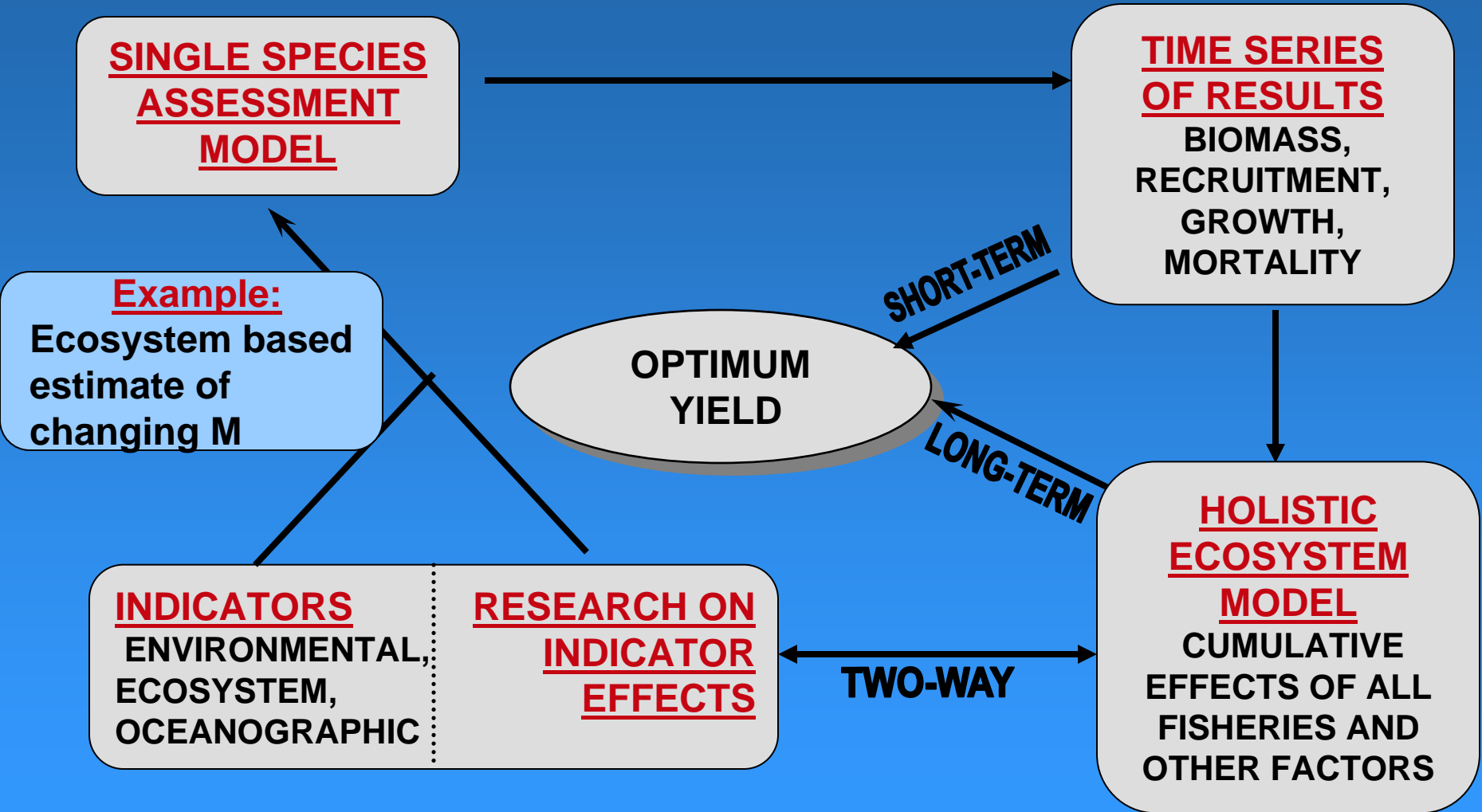


# Data-Poor Principles

- Fact: for data-poor stocks, there is a level of catch that would be overfishing and will eventually deplete the stock
  - We just don't know what it is;
- Estimate of uncertainty should reduce as we get more info, not get larger as we calculate more components of uncertainty;
- Data-poor approach to management should be at least as conservative as the approach used when a data-weak assessment can be done;
- Achieve positive incentive when management buffer is linked to total uncertainty.



# Stock Assessment - Ecosystem Connection



# Assessment Summary

- Assessments are designed to answer management questions
- Variety of methods tuned to diverse data availability scenarios
- Assessments produce estimates of stock abundance, mortality and productivity
- Forecasts provide probability distribution of future stock conditions and yield under alternative harvest scenarios